CHAPTER 3: PRINCIPLES OF DYNAMIC ANALYSIS

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CHAPTER 3 PRINCIPLES OF DYNAMIC ANALYSIS

INTRODUCTION

3-1 PURPOSE.

The purpose of this manual is to present methods of design for protective construction used in facilities for development, testing, production, storage, maintenance, modification, inspection, demilitarization, and disposal of explosive materials.

3-2 OBJECTIVE.

The primary objectives are to establish design procedures and construction techniques whereby propagation of explosion (from one structure or part of a structure to another) or mass detonation can be prevented and to provide protection for personnel and valuable equipment.

The secondary objectives are to:

(1) Establish the blast load parameters required for design of protective structures.

(2) Provide methods for calculating the dynamic response of structural elements including reinforced concrete, and structural steel.

(3) Establish construction details and procedures necessary to afford the required strength to resist the applied blast loads.

(4) Establish guidelines for siting explosive facilities to obtain maximum cost effectiveness in both the planning and structural arrangements, providing closures, and preventing damage to interior portions of structures because of structural motion, shock, and fragment perforation.

3-3 BACKGROUND.

For the first 60 years of the 20th century, criteria and methods based upon results of catastrophic events were used for the design of explosive facilities. The criteria and methods did not include a detailed or reliable quantitative basis for assessing the degree of protection afforded by the protective facility. In the late 1960's quantitative procedures were set forth in the first edition of the present manual, "Structures to Resist the Effects of Accidental Explosions". This manual was based on extensive research and development programs which permitted a more reliable approach to current and future design requirements. Since the original publication of this manual, more extensive testing and development programs have taken place. This additional research included work with materials other than reinforced concrete which was the principal construction material referenced in the initial version of the manual.

Modern methods for the manufacture and storage of explosive materials, which include many exotic chemicals, fuels, and propellants, require less space for a given quantity of explosive material than was previously needed. Such concentration of explosives increases the possibility of the propagation of accidental explosions (one accidental explosion causing the detonation of other explosive materials). It is evident that a requirement for more accurate design techniques is essential. This manual describes rational design methods to provide the required structural protection.

These design methods account for the close-in effects of a detonation including the high pressures and the nonuniformity of blast loading on protective structures or barriers. These methods also account for intermediate and far-range effects for the design of structures located away from the explosion. The dynamic response of structures, constructed of various materials, or combination of materials, can be calculated, and details are given to provide the strength and ductility required by the design. The design approach is directed primarily toward protective structures subjected to the effects of a high explosive detonation. However, this approach is general, and it is applicable to the design of other explosive environments as well as other explosive materials as mentioned above.

The design techniques set forth in this manual are based upon the results of numerous full- and small-scale structural response and explosive effects tests of various materials conducted in conjunction with the development of this manual and/or related projects.

3-4 SCOPE.

It is not the intent of this manual to establish safety criteria. Applicable documents should be consulted for this purpose. Response predictions for personnel and equipment are included for information.

In this manual an effort is made to cover the more probable design situations. However, sufficient general information on protective design techniques has been included in order that application of the basic theory can be made to situations other than those which were fully considered.

This manual is applicable to the design of protective structures subjected to the effects associated with high explosive detonations. For these design situations, the manual will apply for explosive quantities less than 25,000 pounds for close-in effects. However, this manual is also applicable to other situations such as far- or intermediate-range effects. For these latter cases the design procedures were originally developed for explosive quantities in the order of 500,000 pounds which is the maximum quantity of high explosive approved for aboveground storage facilities in the Department of Defense manual, "Ammunition and Explosives Safety Standards", DOD 6055.09-M. **1**\ However, DOD 6055.09-M currently addresses explosive quantities of up to 5,000,000 lbs, and the design procedures, in this document, have been extrapolated for designs to resist accidental explosions on ships of 5,000,000 lbs or more. Although some disasters have involved very high explosive quantities (such as Port Chicago in 1944 which involved around 10,000,000 pounds of explosives), limited testing has been completed at such high quantities (e.g. the Middle North Series used 1,000,000 lbs

TNT, and the Minor Scale and Misty Picture used the equivalent of 8,000,000 lbs TNT). **/1/** Since tests were primarily directed toward the response of structural steel and reinforced concrete elements to blast overpressures, this manual concentrates on design procedures and techniques for these materials. However, this does not imply that concrete and steel are the only useful materials for protective construction. Tests to establish the response of wood, masonry blocks, and plastics, as well as the blast attenuating and mass effects of soil are contemplated. The results of these tests may require, at a later date, the supplementation of these design methods for these and other materials.

Other manuals are available to design protective structures against the effects of high explosive or nuclear detonations. The procedures in these manuals will quite often complement this manual and should be consulted for specific applications.

Computer programs, which are consistent with procedures and techniques contained in the manual, have been approved by the appropriate representative of the US Army, the US Navy, the US Air Force and the Department of Defense Explosives Safety Board (DDESB). These programs are available through the following repositories:

(1) Department of the Army
Commander and Director
U.S. Army Engineer Research and Development Center
Post Office Box 631
Vicksburg, Mississippi 39180-0631
Attn: WESKA

(2) Department of the Navy
Commanding Officer
Naval Facilities Engineering and Expeditionary Warfare Center
1000 23rd Avenue
Port Hueneme, California 93043
Attn: Code CI7

(3) Department of the Air Force
Aerospace Structures
Information and Analysis Center
Wright Patterson Air Force Base
Ohio 45433
Attn: AFFDL/FBR

If any modifications to these programs are required, they will be submitted for review by DDESB and the above services. Upon concurrence of the revisions, the necessary changes will be made and notification of the changes will be made by the individual repositories.

3-5 FORMAT.

This manual is subdivided into six specific chapters dealing with various aspects of design. The titles of these chapters are as follows:

Chapter 1 Introduction

Chapter 2 Blast, Fragment, and Shock Loads

Chapter 3 Principles of Dynamic Analysis

Chapter 4 Reinforced Concrete Design

Chapter 5 Structural Steel Design

Chapter 6 Special Considerations in Explosive Facility Design

When applicable, illustrative examples are included in the Appendices.

Commonly accepted symbols are used as much as possible. However, protective design involves many different scientific and engineering fields, and, therefore, no attempt is made to standardize completely all the symbols used. Each symbol is defined where it is first used, and in the list of symbols at the end of each chapter.

3-6 CHAPTER CONTENTS.

This chapter contains the procedures for analyzing structural elements subject to blast overpressures. These procedures are contained in the next eleven sections; Section 3-7 deals with a simplified discussion of the basic principles of dynamics as well as the procedures for calculating the various components used to perform the dynamic analyses. Presented in Sections 3-8 through 3-15 are resistance-deflection functions for various elements including both one- and two-way panels as well as beam elements. These functions include the elastic, elasto-plastic, and plastic ranges of response. In addition, a discussion of dynamic equivalent systems is presented in Sections 3-16 and 3-17. These include single- and multi-degree-of-freedom systems. Presented in this Section also are methods for calculating load and mass factors required to perform the dynamic analyses.

Sections 3-18 through 3-20 include both a step-by-step numerical integration of an element's motion under dynamic loads utilizing the Acceleration-Impulse-Extrapolation Method or the Average Acceleration Method and design charts for idealized loads. Presented also in these Sections are methods for analyzing elements subjected to impulse type loadings; that is, loadings whose durations are short in comparison to the time to reach maximum response of the elements.

BASIC PRINCIPLES

3-7 GENERAL.

The principles used in the analysis of structures under static load will be reviewed briefly, since the same principles are used in the analysis and design of structures subjected to dynamic loads. Two different methods are used either separately or concurrently in static analysis: one is based on the principle of equilibrium, and the other on work done and internal energy stored.

Under the application of external loads, a given structure is deformed and internal forces developed in its members. In order to satisfy static equilibrium, the vector sum of all the external and internal forces acting on any free body portion of the structure must be equal to zero. For the equilibrium of the structure as a whole, the vector sum of the external forces and the reactions of the foundation must be equal to zero.

The method based on work done and energy considerations is sometimes used when it is necessary to determine the deformation of a structure. In this method, use is made of the fact that the deformation of the structure causes the point of application of the external load to be displaced. The force then does work on the structure. Meanwhile, because of the structural deformations, potential energy is stored in the structure in the form of strain energy. By the principle of energy conservation, the work done by the external force and the energy stored in the members must be equal. In static analysis, simplified methods such as the method of virtual work and the method of the unit load are derived from the general principle of energy conservation.

In the analysis of statically indeterminate structures, in addition to satisfying the equations of equilibrium, it is necessary to include a calculation of the deformation of the structure in order to arrive at a complete solution of the internal forces in the structure. The methods based on energy considerations such as the method of least work and the method based on Castigliano's theorems are generally used.

For the analysis of structures under dynamic loading, the same two methods are basically used; but the load changes rapidly with time and the acceleration velocity and, hence, the inertia force and kinetic energy are of magnitudes requiring consideration. Thus, in addition to the internal and external forces, the equation of equilibrium includes the inertia force and the equation of dynamic equilibrium takes the form of Newton's equation of motion:

$$F - R = Ma \qquad (3\text{-}1)$$

where

F = total external force as a function of time
R = total internal force as a function of time
M = total mass
a = acceleration of the mass

As for the principle of conservation of energy, the work done must be equal to the sum of the kinetic energy and the strain energy:

$$WD = KE + SE \qquad (3\text{-}2)$$

where

WD = work done
KE = kinetic energy
SE = strain energy

and the strain energy includes both reversible elastic strain energy and the irreversible plastic strain energy. Thus, the difference between structures under static and dynamic loads is the presence of inertial force (*Ma*) in the equation of dynamic equilibrium, and of kinetic energy in the equation of energy conservation. Both terms are related to the mass of the structure; hence, the mass of the structure becomes an important consideration in dynamic analysis.

In the dynamic analysis of structures, both the energy balance equation and the force balance equation are applied with explicit description of the external forcing function *F*, and the internal resisting forcing function *R*. The difference between these forcing functions is the inertia force as described above. The following is a discussion of the details of how these forces are utilized in the design of structures which respond in the ductile mode.

In the design of a structure to resist the blast from an HE explosion, the total external force acting on the structure can be obtained by the principles discussed Chapter 2. The design method also consists of the determination of the total internal force, i.e. the resistance of the structure required to limit calculated deflections of the individual members and the structure as a whole under the external force (blast loading), to within prescribed maximum values. The determination of the resistance of the individual members of the structure is presented in Sections 3-8 through 3-17. Subsequent sections of this manual present the principles and methods of dynamic analysis and equations, charts, and procedures for design.

RESISTANCE – DEFLECTION FUNCTIONS

3-8 INTRODUCTION.

Under the action of external loads, a structural element is deformed and internal forces set up. The sum of these internal forces tending to restore the element to its unloaded static position is defined as the resistance. The resistance of a structural element is a reactive force associated with the deflection of the element produced by the applied load. It is convenient to consider the resistance as an equivalent load in the same manner as the applied load, but opposite in direction. The variation of the resistance vs. displacement is expressed by a resistance-deflection function and may be represented graphically. An idealized resistance-deflection function for an element spanning in two directions and covering in the complete flexural range to incipient failure is shown in Figure 3-1 (+).

As load is applied to a structural element, the element deflects and, at any instant, exerts a resistance to further deformation, which is a function of its units stiffness *K*, until the ultimate unit resistance r_u (total resistance is r_u where *A* is the element area) of

the element is reached at deflection X_p. The initial portion of the resistance-deflection diagram is composed of the elastic and elasto-plastic ranges, each with its corresponding stiffness, the transition from one range to another occurring as plastic hinges are formed at points of maximum stress (yield lines). The number of elasto-plastic ranges required before the ultimate resistance of a particular element is reached depends upon the type and number of supports (and the placement of reinforcing steel in reinforced concrete elements). For example a beam with simple supports subjected to uniformly distributed loads needs only one plastic hinge to develop the ultimate resistance (or full plastic strength) of the element; whereas for the same beam fixed at both ends, more than one plastic hinge is required.

In subsequent paragraphs, various procedures, equations and illustrations are presented to enable the designer to determine the resistances of both one- and two-way elements. The procedures outlined apply mainly to reinforced concrete elements and so do the equations appearing in the text, unless the equations are given as part of an illustrative example. However, they can also be used for structural steel elements as well as other structural elements such as aluminum, plastics, etc. Equations have been derived for specific cases most often encountered in practice. These are applicable for structural steel and reinforced concrete elements of uniform thickness in both the horizontal and vertical directions. Before the equations and figures can be used for reinforced concrete element, however, the reinforcing steel across any yield line must have a uniform distribution in both the vertical and horizontal directions; however, the reinforcement across the positive yield lines can be different from that across the negative yield lines and the reinforcing pattern in the vertical direction different from that in the horizontal direction.

Regardless of whether it is a reinforced concrete or structural steel element, any opening in the element must be compact in shape and small in area, compared to the total area of the element.

3-9 ULTIMATE RESISTANCE.

3-9.1 General.

The ultimate resistance of an element depends upon:

(1) The distribution of the applied loads.

(2) The geometry of the element (length and width).

(3) The number and type of supports.

(4) The distribution of the moment capacity in the element.

The distribution of the loads depends upon the design range of the element; i.e., high, intermediate or low pressure. For intermediate and low pressure ranges, it can be assumed that the pressure is uniform across the surface of the element although it varies with time. At high pressure ranges, however, the blast loads are variable across the surface of the element. However, for structural steel elements and concrete

elements utilizing laced reinforcement, or for concrete elements with standard shear reinforcement which sustain relatively small deflections, a good estimate of the resulting deflections can be made using the resistance functions conforming to those of uniformly loaded elements.

The other factors that affect the ultimate resistance of an element are predetermined by the requirements of the protective structure (where the element is used) and the magnitude of the blast output.

3-9.2 One-Way Elements.

The ultimate resistance of a. one-way reinforced concrete element with an elastic distribution of its reinforcing steel is based on the moment capacity at first yield since all critical sections yield simultaneously. For one-way reinforced concrete elements (such as beams or slabs) with non-elastic distribution of reinforcing steel and for structural steel elements, the ultimate resistance is a function of the moment capacity at the first yield plus the added moment capacity due to subsequent yielding at other critical sections.

Values of the ultimate resistance for one-way elements are shown in Table 3-1 (+) where the following symbols are used:

M_N = ultimate negative unit moment capacity at the support.
M_p = ultimate positive unit moment capacity at midspan.
L = length
r_u = ultimate unit resistance
R_u = total ultimate resistance

Table 3-1 (+) applies to both beams and slabs. However, special attention must be paid to the units used for the respective element. The moment capacity of a slab is expressed for a unit strip of the slab (inch-pounds per inch) whereas the total moment capacity (inch-pounds) is considered for a beam. Consequently, the resistance of a slab is expressed in load per unit area (psi) where the resistance of a beam is expressed in load per length along the beam (pounds per inch).

3-9.3 Two-Way Elements.

The amount of data available on the limit analysis of rectangular steel plates is very limited. However, an elementary approach imagines a mechanism formed of straight yield lines, as is customary in reinforced concrete. This approach for reinforced concrete elements will be considered appropriate for structural steel elements.

In the design of two-way reinforced concrete elements, it is not necessary to define accurately the stress distribution during the initial and intermediate stages of loading since the ultimate load capacity can be readily determined by the use of yield line procedures. The yield line method assumes that after initial cracking of the concrete at points of maximum moment, yielding spreads until the full moment capacity is developed along the length of the cracks on which failure will take place. Several

illustrative examples of the simplified yield or crack lines for two-way elements are illustrated in Figure 3-2 (+).

In using the yield line solution, the initial step is to assume a yield line pattern (as shown in Figure 3-2 (+)) applying the following rules:

(1) The yield lines act as plastic hinges of a collapse mechanism made up of plane segments. They must be straight lines forming axes of rotation for the movements of the segments.

(2) The supports of the slabs will act as axes of rotation. A yield line may form along a fixed support and an axis of rotation will pass over a column.

(3) For compatibility of deformations, a yield line must pass through the intersection of the axes of rotation of the adjacent slab segments.

Tests indicate that the actual location and extent of these lines on reinforced concrete elements differ only slightly at failure from the theoretical ones. Use of the idealized yield lines results in little error in the determination of the ultimate resistance and the error is conservative for design.

The corner sections of two-way elements are stiff in comparison to the remainder of the member; therefore, the reinforcement strains associated with the reduced rotations at these sections will be less. To account for the corner effects, the design of any one particular section of a two-way element should consider a variation of the moment capacity along the yield lines rather than a uniform distribution.

This variation is approximated by taking the full moment capacity along the yield lines, except in the corners where two-thirds of the moment capacity over the lengths described in Figure 3-3 (+) are used. The variation applies to both the negative moment capacities along the supports and the positive moment capacities at the interior. The ultimate unit resistance can be determined from the yield line pattern using either the principle of virtual work or the equations of equilibrium. Each approach has its advantages; in general, the virtual work method is easier in principle, but difficult to manipulate algebraically since it involves differentiating a usually complex mathematical expression for a minimum value of resistance. The equilibrium method, which is used in this manual, also has its disadvantages. Since equilibrium requires that the shear forces acting on each side of a yield line have to be equal and opposite, correction forces (also known as nodal forces) have to be introduced around openings in two-way members and at free edges, and these correction forces may not be available from simple analysis. However, in three of the six cases shown in Figure 3-2 (+), (cases c, e, f), nodal forces exist; but their effects are negligible.

In order to calculate the ultimate unit resistance r_u of a two-way element, the equation of equilibrium of each sector formed by the yield lines is expressed in terms of the moments produced by the internal and external forces. The sum of the resisting moments acting along the yield lines (both positive and negative) of each sector is

equated to the moment produced by the applied load about the axis of rotation (support of the sector), assuming that the shear forces are zero along the positive yield lines.

$$\Sigma M_N + \Sigma M_p = Rc = r_u Ac \qquad (3\text{-}3)$$

where

M_N = *sum of the ultimate unit resisting moments acting along the support (negative yield lines)*
M_p = *sum of the ultimate unit resisting moments acting along the interior failure lines (positive yield lines)*
R = *total ultimate resistance of the sector*
c = *distance from the centroid of the load to the line of rotation of the sector*
r_u = *ultimate unit resistance of the sector*
A = *area of the sector*

Once the equations of equilibrium are known for all sectors, the ultimate resistance is obtained either by solving the equations simultaneously, or by a trial and error procedure noting that the unit resistance of all sectors must be equal.

To illustrate the above procedure (Equation 3-3), consider the two-way concrete element shown in Figure 3-3 (+) which is fixed on three edges and free on the fourth, and where the nomenclature is as follows:

L = *length of element*
H = *height of element*
x = *yield line location in horizontal direction*
y = *yield line location in vertical direction*
M_{VN} = *ultimate unit negative moment capacity in the vertical direction*
M_{VP} = *ultimate unit positive moment capacity in the vertical direction*
M_{HN} = *ultimate unit negative moment capacity in the horizontal direction*
M_{HP} = *ultimate unit positive moment capacity in the horizontal direction*

The nomenclature as stated in the paragraph above is strictly applicable to two-way elements which are used as walls. However, when roof slabs or other horizontal elements are under consideration, the preceding nomenclature will also be applicable if the element is treated as being rotated into a vertical position.

The first step in the solution is to assume the location of the yield lines as defined by the coordinates *x* and *y*. It should be noted that in some cases, because of geometry, the value of *x* and *y* will be known and therefore need not be evaluated. In this example, the negative reinforcement in the horizontal direction at opposite supports is assumed to be equal; therefore, the vertical yield line is located at the center of the span and the value of *x* is numerically equal to *L*/2 (a, Figure 3-3 (+)). However, in other cases, neither the

location of x nor y will be known, and the solution will require the determination of both coordinates.

Once the yield lines have been assumed, the distribution of the resisting moments along the yield lines is determined. In the case at hand, the reduced moments, as a result of the increased stiffness at the corners, act over lengths equal to $x/2$ and $y/2$ in the horizontal and vertical directions, respectively (a, Figure 3-3 (+)). The equations of equilibrium are then written for each sector with the use of the free body diagrams (b, Figure 3-3). For the triangular sector I:

$$M_{VN} = (2/3)M_{VN}\,(L/4 + L/4) + M_{VN}\,(L/2) = (5/6)M_{VN}\,L \qquad 3\text{-}4$$

$$M_{VP} = (2/3)M_{VP}\,(L/4 + L/4) + M_{VP}\,(L/2) = (5/6)M_{VP}\,L \qquad 3\text{-}5$$

$$C_I = y/3 \qquad 3\text{-}6$$

$$R_I = (M_{VN} + M_{VP})/C_I = [5L(M_{VN} + M_{VP})]/(2y) \qquad 3\text{-}7$$

$$A_I = Ly/2 \qquad 3\text{-}8$$

$$r_u(\text{Sector I}) = R_I/A_I = [5(M_{VN} + M_{VP})]/y^2 \qquad 3\text{-}9$$

For the trapezoidal sector II, a similar procedure gives

$$M_{HN} = (2/3)M_{HN}\,(y/2) + M_{HN}\,(H - y/2) = M_{HN}\,(H - y/6) \qquad 3\text{-}10$$

$$M_{HP} = (2/3)M_{HP}\,(y/2) + M_{HP}\,(H - y/2) = M_{HP}\,(H - y/6) \qquad 3\text{-}11$$

$$C_{II} = (1/3)(L/2)[2(H-y) + H]/(H + H - y) = [L(3H - 2y)]/6(2H - y) \qquad 3\text{-}12$$

$$R_{II} = (M_{HN} + M_{HP})/C_{II} = [(6H - y)(2H - y)(M_{HN} + M_{HP})]/L(3H - 2y) \qquad 3\text{-}13$$

$$A_{II} = 1/2)(L/2)(H + H - y) = [L(2H - y)]/4 \qquad 3\text{-}14$$

$$r_u(\text{Sector II}) = R_{II}/A_{II} = [4(M_{HN} + M_{HP})(6H - y)]/L^2(3H - 2y) \qquad 3\text{-}15$$

Equations 3-9 and 3-15 are the equations of equilibrium for the triangular (I) and the trapezoidal (II) sectors, respectively. As mentioned previously, these equations can be solved simultaneously or by a trial and error procedure. In the latter method, values of y are substituted into both equations until r_u (sector I) is equal to r_u (sector II).

If a numerical solution based on the above procedure (Equation 3-3) yields negative values for either x, y or r then the assumed yield line location is wrong. In this example, the only other possible yield line pattern ($x \leq L/2$) would be as shown in Figure 3-2c (+).

The solution of Equation 3-3 is universally applicable for any two-way element. If the negative reinforcement in the horizontal direction had been unequal at the opposing supports, the value of $x = L/2$ would have changed, and all three sectors would have had to be considered to determine x, y and hence, r_u.

Simultaneous solution of Equations 3-9 and 3-15 reveals that the locations of the yield lines are a function of the ratio of the spans *L*/*H* and the ratio of the sum of the unit vertical to horizontal moment capacities as follows:

$$r_u(\text{Sector I}) = r_u(\text{Sector II}) \qquad \text{3-16}$$

$$5(M_{VN} + M_{VP})/y^2 = [4(M_{HN} + M_{HP})(6H - y)]/L^2(3H - 2y) \qquad \text{3-17a}$$

$$L^2(M_{VN} + M_{VP})/H^2(M_{HN} + M_{HP}) = [4y^2(6 - y/H)]/[5H^2(3 - 2y/H)] \qquad \text{3-17b}$$

$$(L/H)[(M_{VN} + M_{VN})/(M_{HN} + M_{HP})]^{1/2} = (y/H)[(4(6 - y/H)/(5(3 - 2y/H))]^{1/2} \qquad \text{3-17c}$$

Equation 3-17c, which relates the location of the yield lines to the moment capacity of the element, is used to plot Figure 3-6 (+). Knowing the location of the yield lines, the resistance of the two-way element can be obtained from either Equation 3-9 or 3-15 which are also presented in Table 3-2 (+).

Using the procedure outlined above, the values of the ultimate unit resistances for several two-way elements with various support conditions are given in Table 3-2 (+) and Table 3-3 (+), the nomenclature confirming to that previously listed. Table 3-2 covers the special cases where opposite supports provide the same degree of restraint thus resulting in symmetrical yield line patterns. Table 3-3 deals with the general cases when the yield line patterns are not symmetrical (that is, when opposite supports provide different restraints). Yield line location ratios *x*/*L* and *y*/*H* for the same elements are depicted in Figure 3-4 through Figure 3-20.

Figure 3-4 (+) and Figure 3-5 (+) show the location of the yield lines for two-way elements with two adjacent edges supported and the other two free. In each of these figures eight curves are shown which represent different ratios of the positive to the negative moment capacities in both the vertical and horizontal directions. Figure 3-6 through Figure 3-16 illustrate the yield line location for two-way elements with three edges supported and one edge free. Figure 3-6 (+) and Figure 3-11 (+) covers the case when the yield line pattern is symmetrical (opposite supports provide the same degree of restraint). Figure 3-17 through Figure 3-20 show the yield line location for two-way elements with four sides supported.

Figure 3-17 (+) covers the special case when opposite supports provide the same degree of restraint, thus resulting in a symmetrical yield pattern. An example illustrating the use of some of these figures is provided in Appendix 3A.

3-9.4 Openings in Two-Way Elements.

The use of openings in two-way elements, whether for access as a door opening or for visual communication as in the case of observation ports, is permissible with certain reservations. It is difficult to state exact rules concerning openings, but their effect on the design is generally a function of location, size and shape.

Small compact openings with approximate areas of less than 5 percent of the panel area located away from regions of high stress can usually be ignored in the design. However, as in the case of conventional design, reinforcement at least equal to the amount interrupted should be placed adjacent to the opening. For example, in Figure 3-21 (+), the openings shown in (a) and (b) can be disregarded. If the opening in (b) were made more rectangular as in (c), then the design must be modified to account for the change in the yield lines and, hence, the change in the resistance. This change in resistance is a function of both the shape and the location of the opening.

Door openings invariably require special analysis because of their size. As depicted in (d), (e) and (f) of Figure 3-21 (+), the presence of door openings causes gross relocations of the yield lines which generally propagate from the corners of the openings. Since the door also sustains the blast loading, concentrated line loads are present around the periphery of such openings. These concentrated loads must be included in the analysis since they change the resistance. As previously outlined for solid elements and for this case also, the yield line locations are assumed and each sector is individually analyzed. The presence of line loads modifies Equation 3-3 to

$$\Sigma M_N + \Sigma M_p = r_u Ac + M_c \qquad 3\text{-}18$$

where M_c is the moment of the concentrated loads about the line of rotation of the sector being considered. Solution of elements with openings is most easily accomplished through a trial and error procedure by setting up the simultaneous equations for each sector and assuming various values of x and y until the several values of r_u agree to within a few percent.

3-10 POST-ULTIMATE RESISTANCE.

In general, the two-way elements described in this manual exhibit a post-ultimate resistance after partial failure occurs, as indicated in Figure 3-1 (+). Prior to partial failure, the element is spanning in two directions with a resistance equal to the ultimate resistance r_u. At a particular deflection, denoted as X_1, failure occurs along one side or two opposite sides, and the element then spans in one direction with the reduced post-ultimate unit resistance r_{up} until complete failure occurs at deflection X_u. One-way elements do not exhibit this behavior.

The location of the yield lines determines the presence or absence of this range. If the yield lines emanating from the corners of the elements bisect the 90-degree corner angle, then all supports fail simultaneously and there is no post-ultimate range. As previously shown, the location of the yield lines for a particular element is a function of L/H and the ratio of the unit vertical to horizontal moment capacities. Post-ultimate resistances for two-way elements are shown in Table 3-4 (+).

3-11 PARTIAL FAILURE AND ULTIMATE DEFLECTION.

Partial failure deflection X_1, for two-way elements and ultimate deflections X_u for both one-way and two-way elements are a function of the angle of rotation of the element at its supports and the geometry of the sectors formed by the position yield lines.

Once the ultimate resistance r_u is reached (full moment capacity developed along the yield lines), the structural element becomes a mechanism which rotates with no further increase in either the moment or curvature between the hinges. For one-way elements, the rotation continues and the deflection increases until either the maximum deflection X_m is reached, or failure occurs at Θ_{max}. The equations for both the maximum deflection X_m in the range $0 \leq X < X_u$, and the ultimate deflection X_u, as a function of the rotation angle Θ are given in Table 3-5 (+) for several one-way elements.

The maximum support rotation at failure, Θ_{max}, will vary with the material type and geometry of the element. The criteria for partial and incipient failure for concrete and structural steel elements can be found in Chapters 4 and 5 respectively.

For two-way elements, the rotations of all the sectors must be considered in order to define the deflections of partial and incipient failure. Prior to partial failure ($0 \leq X_m \leq X_1$), the maximum deflection is a function of the larger angle of rotation formed along either the vertical or horizontal supports. At deflection X_1, this larger angle equals Θ_{max} and failure occurs along this support. Beyond this point, the element spans in one direction until the angle of rotation at the adjacent supports (in the direction opposite to that at which failure has already occurred) reaches Θ_{max}, at which time total collapse occurs ($X_m = X_u$).

To illustrate the above, consider a two-way element (Figure 3-22 (+)) which is fully restrained on four edges and whose positive yield lines are defined by $H/2 < x < L/2$ and $y = H/2$. The support rotation limit for this element is 12-degrees. Denoting Θ_H as the angle of rotation in the horizontal direction (along vertical supports) and Θ_V as the vertical angle of rotation (along horizontal supports), the maximum deflection X_m at the center of the element prior to reaching the deflection X_1 is

$$X_m = (H \tan \Theta_v)/2 \qquad 3\text{-}19$$

and partial failure occurs at deflection X_1 when $\Theta_v = \Theta_{max}$ *(which is 12^0 in* Figure 3-22 (+)*)*

$$X_1 = (H \tan \Theta_{max})/2 \qquad 3\text{-}20$$

Referring to Figure 3-22 (+), the deflected shape at deflection X_1 is indicated by the solid line and Θ_H has value *ß* which is defined as

$$ß = \tan^{-1}(X_1/x) = \tan^{-1}(H \tan \Theta_{max}/2x) \qquad 3\text{-}21$$

As the element continues to deflect the angle of rotation Θ_H increases, its magnitude becoming equal to

$$\Theta_H = \lambda + ß \qquad 3\text{-}22$$

where λ is the angular rotation in excess of $ß$. For a two-way element which undergoes partial failure but does reach incipient failure, the maximum deflection in the range $X_1 \leq X_m \leq X_u$ becomes

$$X_m = x \tan \Theta_H + [(L/2) - x)] \tan (\Theta_H - ß) \qquad 3\text{-}23$$

When Θ_H equal Θ_{max}, the ultimate deflection X_u at incipient failure is

$$X_u = x \tan \Theta_{max} + [(L/2 - x)] \tan [\Theta_{max} - \tan^{-1} (H \tan \Theta_{max}/(2x))] \qquad 3\text{-}24$$

Equations 3-19 through 3-24 are specifically for two-way elements described in Figure 3-22 (+) and will vary for other two-way elements with different material properties and geometry.

The maximum deflection X_m for two-way elements with differing edge conditions in the ranges $0 \leq X_m \leq X_1$, and $X_1 < X_m \leq X_u$ as a function of the rotation angles Θ_H and Θ_V are given in Table 3-6 (+), along with the values of partial failure (X_1) and ultimate (X_u) deflections. The support which fails at partial deflection X_1 is also indicated.

3-12 ELASTO-PLASTIC RESISTANCE.

As stated in Section 3-8, the initial portion of the resistance function (Figure 3-1 (+)) generally is composed of an elastic and one or more elasto-plastic ranges. The elastic unit resistance r_e is defined as the resistance at which first yield occurs; similarly, the elasto-plastic unit resistance r_{ep} is the resistance at which second yields subsequently occur. Where all hinges form in a member at one time, r_e will be equal to the ultimate unit resistance r_u; where two or more hinges are formed at separate times, the maximum value of r_{ep} will be equal to r_u (depending upon the hinges formed, one or more values of r_{ep} may exist).

These resistances for one-way elements are listed in Table 3-7 (+). In those cases where the elasto-plastic resistance is equal to the ultimate resistance, the value can be determined from Table 3-1 (+).

The determination of the elasto-plastic resistances of two-way elements is more complicated than that for one-way elements, since the resistance varies with the span ratio and, in the case of reinforced concrete elements, with the placement of the reinforcement. Data for calculating the resistances of two-way elements during the elasto-plastic ranges (graphically summarized in Figure 3-23 (+)) are presented in Figure 3-24 through Figure 3-38.

Figure 3-24 through Figure 3-26 are for a two-way element supported on two adjacent sides and free at the others. Figure 3-27 through Figure 3-32 are for a two-way element supported on three sides and free on the fourth, while Figure 3-33 through Figure 3-38 are for elements fixed on four sides. The resistances in each range can readily be determined using the coefficients *ß*, the subscript referring to the points listed in the accompanying illustration.

For example, in Figure 3-27 (+), for an element fixed on three sides and free on the fourth, if the ultimate unit resisting moments M_u are known for points 1, 2 and 3, a resistance r for each point can be calculated from

$$r = M_u / ßH^2 \qquad 3\text{-}25$$

where the values of *ß* are found in Figure 3-27 (+). The smallest value of resistance r (say at point 2), corresponds to the first yield and is equal to r_e. Next, the moments at the remaining two points are computed for this value of r_e, and the differences between these and the ultimate values are determined. These differences represent the remaining moment capacities available for additional load. At r_e, the element's supports become free, fixed, and simply-supported on opposite sides. Using the moment differences and entering Figure 3-29 (+) two values of the change in resistance can be calculated as above, the smaller being Δr and therefore:

$$r_{ep} = r_e + \Delta r \qquad 3\text{-}26$$

In similar fashion, the resistance at the end of each range can be determined until the ultimate unit resistance r_u is reached.

3-13 ELASTO-PLASTIC STIFFNESSES AND DEFLECTIONS.

The slopes of the elastic and elasto-plastic ranges of the resistance function are defined by the stiffness *K* of the element:

$$K = r/X \qquad 3\text{-}27$$

where r is the unit resistance and X is the deflection corresponding to the value of r. The elastic range stiffness is denoted as K_e, the elasto-plastic range as K_{ep}, while in the plastic range the stiffness is zero.

Typical resistance-deflection functions used for design are shown in Figure 3-39 (+). One- and two-step systems are generally used for one-way elements while two- and three-step systems are used for two-way elements. Two way elements fixed on all four sides will exhibit a four step system. As can be seen from the figure, the elastic range stiffness

$$K_e = r_e / X_e \qquad 3\text{-}28$$

the elasto-plastic stiffness for a two-step system

$$K_{ep} = (r_u - r_e) / (X_p - X_e) \qquad 3\text{-}29$$

and for a three-step system, the elasto-plastic stiffnesses

$$K_{ep} = (r_{ep} - r_e) / (X_{ep} - X_e) \qquad 3\text{-}30$$

and

$$K'_{ep} = (r_u - r_{ep}) / (X_p - X_{ep}) \qquad 3\text{-}31$$

The elastic and elasto-plastic stiffnesses of one-way elements are given in Table 3-8 (+) as a function of the modulus of elasticity E, moment of inertia I, and span length. Knowing the resistances and stiffnesses, the corresponding elastic and elasto-plastic deflections can be computed from the above equations.

The determination of the elasto-plastic stiffnesses and deflections of two-way elements is more complicated than for one-way elements since another variable, namely, the aspect ratio L/H, must be considered. For two-way elements, the deflections at the end of each range of behavior is obtained from the γ coefficients presented in Figure 3-24 (+) through Figure 3-38 (+). The deflection for each range of behavior is obtained from

$$XD = \gamma r H^4 \qquad 3\text{-}32$$

where D, the flexural rigidity of the element is defined as

$$D = EI/(1-\nu^2) \qquad 3\text{-}33$$

E is the modulus of elasticity, *I* is the moment of inertia per unit width (where the width is perpendicular to span direction), and ν is Poisson's ratio. It must be realized that except for the elastic range, the values of *X* (the displacement) and *r* in Equation 3-32 represent change in deflection and resistance from one range of behavior to another. Therefore, for two-way members the change in deflection and resistance (as previously explained) is obtained from Figure 3-24 through Figure 3-38 and the stiffnesses are computed from Equations 3-28 through 3-33.

3-14 RESISTANCE-DEFLECTION FUNCTIONS FOR DESIGN.

3-14.1 General.

The resistance-deflection function used for design depends upon the maximum permitted deflection according to the design criteria of the element being considered. This maximum deflection X_m can be categorized as either limited or large. In the limited deflection range, the maximum deflection of the system is limited to the elastic, elasto-plastic and plastic ranges. When the maximum deflection falls in the large deflection range, the response of the system is mainly within the plastic range and the elastic and elasto-plastic ranges need not be considered. The error resulting from the omission of the elastic and elasto-plastic portions in this analysis is negligible.

The support rotation that corresponds to limited deflection varies for the different materials used in protection design. The response criteria for each material are obtained from the chapter that describes the design procedures for that material.

3-14.2 Limited Deflections.

When designing for limited deflections, the maximum deflection X_m of the element is kept within the elastic, elasto-plastic, and limited plastic ranges, and the resistance-deflection function for design takes the form shown in Figure 3-39 a, b, and c (+) for a one-step system, a two-step system, and a three-step system, respectively. The design charts presented in Section 3-19.3 were established for a one-step system; for two- and three-step systems, these charts can be used if the resistance-deflection functions are replaced with equivalent elastic resistance-deflection functions defined by K_E and X_E as indicated by the dotted lines in Figure 3-39. The equivalent elastic stiffness K_E and the equivalent maximum elastic deflection X_E are calculated such that the area under the dotted curve is equal to the area under the solid curve, thereby producing the same potential energy in each system. The equivalent maximum elastic deflection X_E for the two-step and three-step systems shown is expressed by Equations 3-34 and 3-35, respectively.

$$X_E = X_e + X_p(1 - r_e/r_u) \qquad 3\text{-}34$$

$$X_E = x_e\,(r_{ep}/r_u) + X_{ep}(1 - r_e/r_u) + X_p(1 - r_{ep}/r_u) \qquad 3\text{-}35$$

The equivalent elastic stiffness K_E in each case is equal to

$$K_E = r_u/X_E \qquad 3\text{-}36$$

One-way elements exhibit one- and two-step resistance deflection curves depending on the type of supports. Consequently, the equivalent elastic stiffness K_E is given for one-way elements in Table 3-8 (+). The equivalent elastic deflection can then be calculated from Equation 3-36. Two-way elements generally exhibit two- and three-step resistance-deflection curves which are a function of not only the type of supports but also of the aspect ratio L/H of the element. The equivalent elastic deflection X_E of the element under consideration must be calculated from Equations 3-34 and 3-35 for two- and three-step systems, respectively. The value of K_E for the system can then be obtained from Equation 3-36.

3-14.3 Large Deflections.

When designing for a large deflection, it can be assumed without significant error that the resistance rises instantaneously from zero to its ultimate value r_u at the onset of the blast loading thus neglecting the elastic and elasto-plastic ranges. The design resistance function for one-way elements is approximated by a constant plastic range resistance as shown in Figure 3-40a (+), while for two-way elements, the resistance function becomes that shown in Figure 3-40b (+), where the maximum deflection X_m can be either smaller or larger than the partial failure deflection X_1.

3-15 SUPPORT SHEARS OR REACTIONS.

Support shears or reactions are a function the applied load and the maximum resistance attained by an element, its geometry and yield line location. However, for short duration blast loads, the support shears can be reasonably estimated by neglecting the applied load. Therefore, the ultimate support shear can be assumed to be developed when the resistance reaches the ultimate value, r_u.

Equations for the ultimate support shears V_s for one-way elements are given in Table 3-9 (+). For those cases where an element does not reach its ultimate resistance, the support shears are obtained based upon elastic theory for the actual resistance r attained by the element.

For two-way elements, the ultimate shears acting at each section are calculated by use of the "yield line procedure" previously outlined for the determination of the ultimate resistance r_u. The shear along the support is assumed to vary in the same manner as the moment varies (2/3 V at the corners and V elsewhere) to account for the higher stiffness of the corners (Figure 3-41 (+)). Since the shear is assumed to be zero along the interior (usually positive) yield lines, the total shear at any section of a sector is equal to the resistance r_u times the area between the section being considered and the positive yield lines. Referring to Figure 3-41, the support shear V_{sV} for the triangular sector I is

$$(2/3)V_{sV}(L/4 + L/4) + V_{sV}(L/2) = r_u(Ly/2) \qquad 3\text{-}37$$

$$V_{sV} = 3r_u y/5 \qquad 3\text{-}38$$

and for the trapezoidal sector II

$$(2/3)V_{sH}(y/2) + V_{sH}(H - y/2) = r_u(L/2)[(H - y + H)/2] \qquad 3\text{-}39$$

$$V_{sH} = [3r_u L(2-y/H)]/[2(6 - y/H)] \qquad 3\text{-}40$$

Values of the ultimate support shears V_{sH} and V_{sV} for several two-way elements derived as above are presented in Table 3-10 (+) and Table 3-11 (+). Table 3-10 gives the ultimate support shears for the case where opposite supports provide the same degree of restraint resulting in symmetrical yield line patterns. Table 3-11 is for completely general situations where opposing supports provide different degrees of restraint and result in the formation of unsymmetrical yield lines. In these cases, the ultimate support shears are not equal at opposing supports. For the situations where the ultimate resistance of an element is not attained, the support shears are less than the ultimate value. The proportion of the total load along each support as well as the distribution of the shears along the support is assumed to be the same as previously cited for the ultimate support shear. Therefore, the support shears corresponding to the resistance r of the element is obtained from the equations presented in Table 3-10 (+) and Table 3-11 (+) by replacing r_u with the actual resistance attained (r_e, r_{ep}, etc.).

Figure 3-1 Typical Resistance-Deflection Function for Two-Way Element

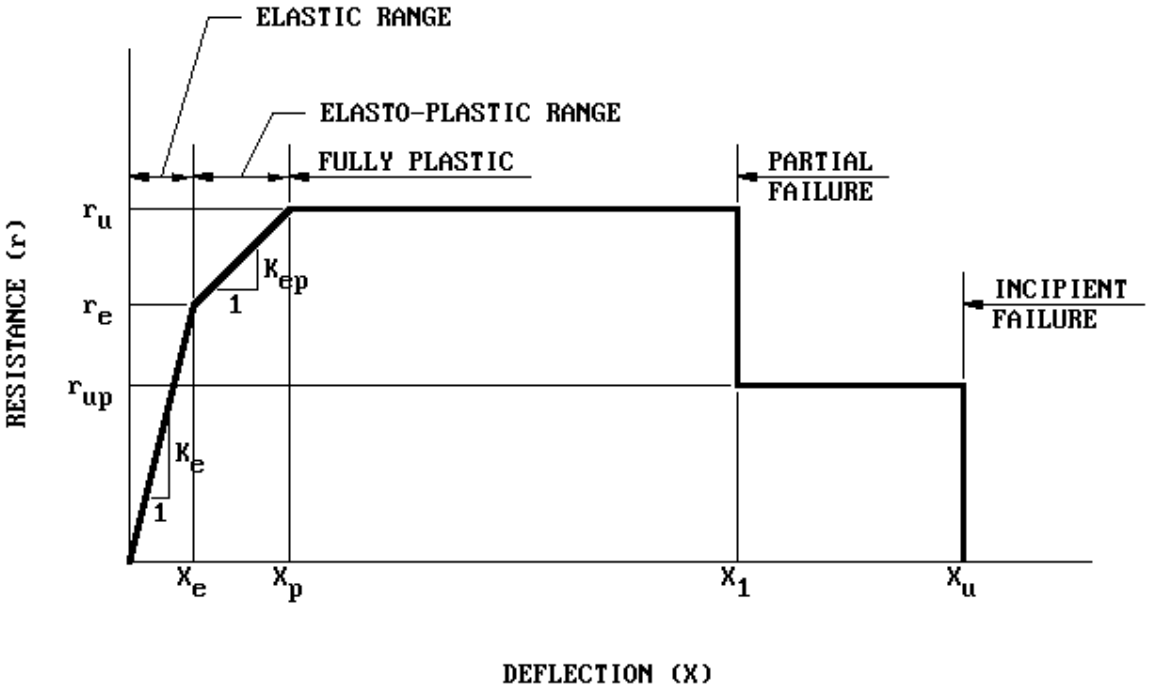


Figure 3-2 Idealized Yield Line Locations for Several Two-Way Elements

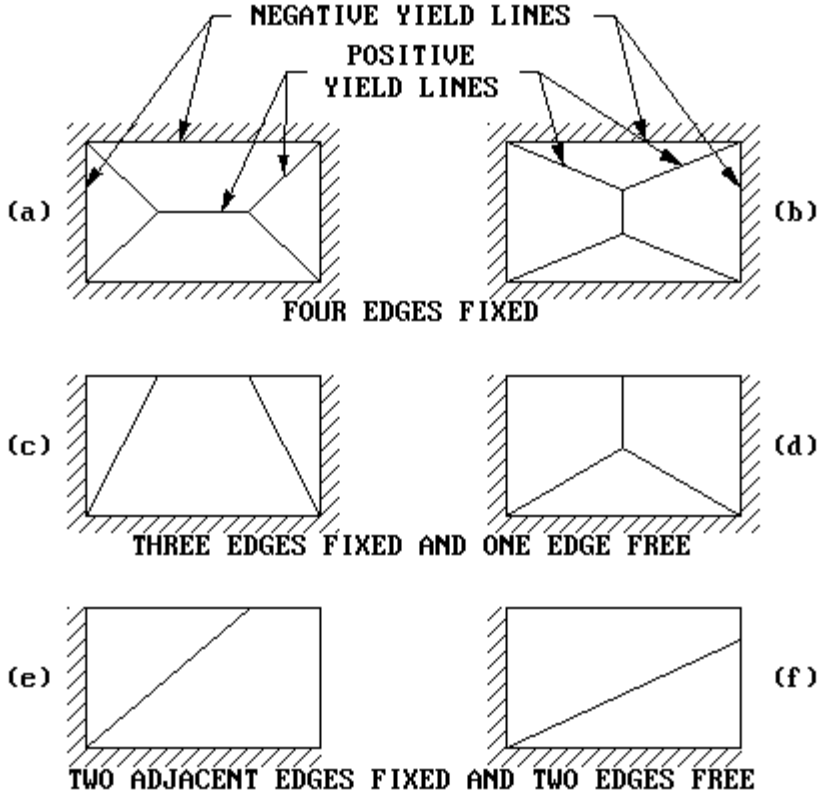
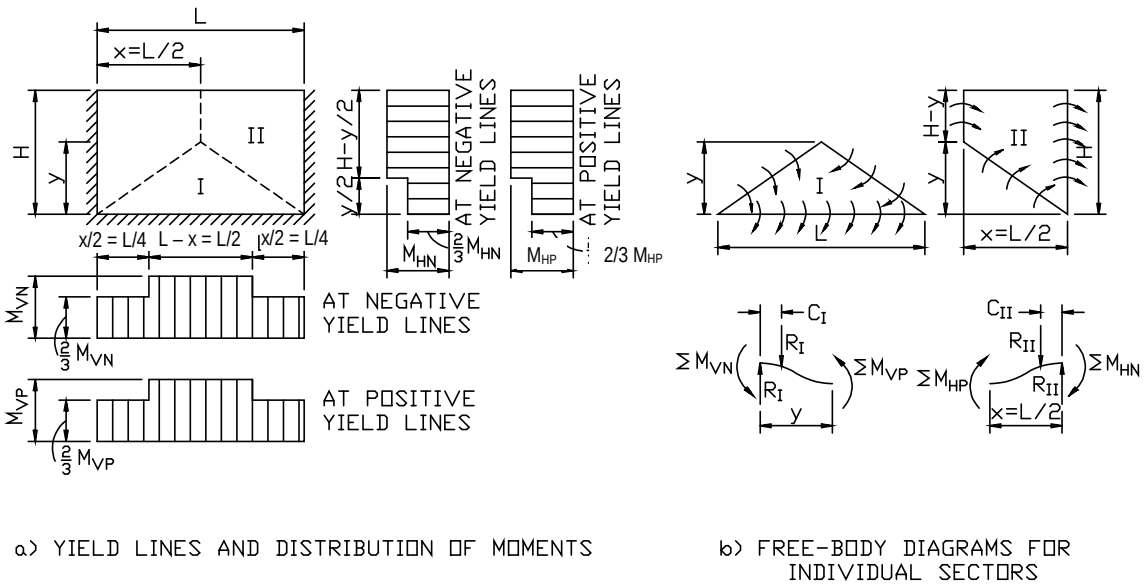


Figure 3-3 Determination of Ultimate Unit Resistance



a) YIELD LINES AND DISTRIBUTION OF MOMENTS

b) FREE-BODY DIAGRAMS FOR INDIVIDUAL SECTORS

Figure 3-4 Location of Yield Lines for A Two-Way Element with Two Adjacent Edges Supported and Two Edges Free (values of *x*)

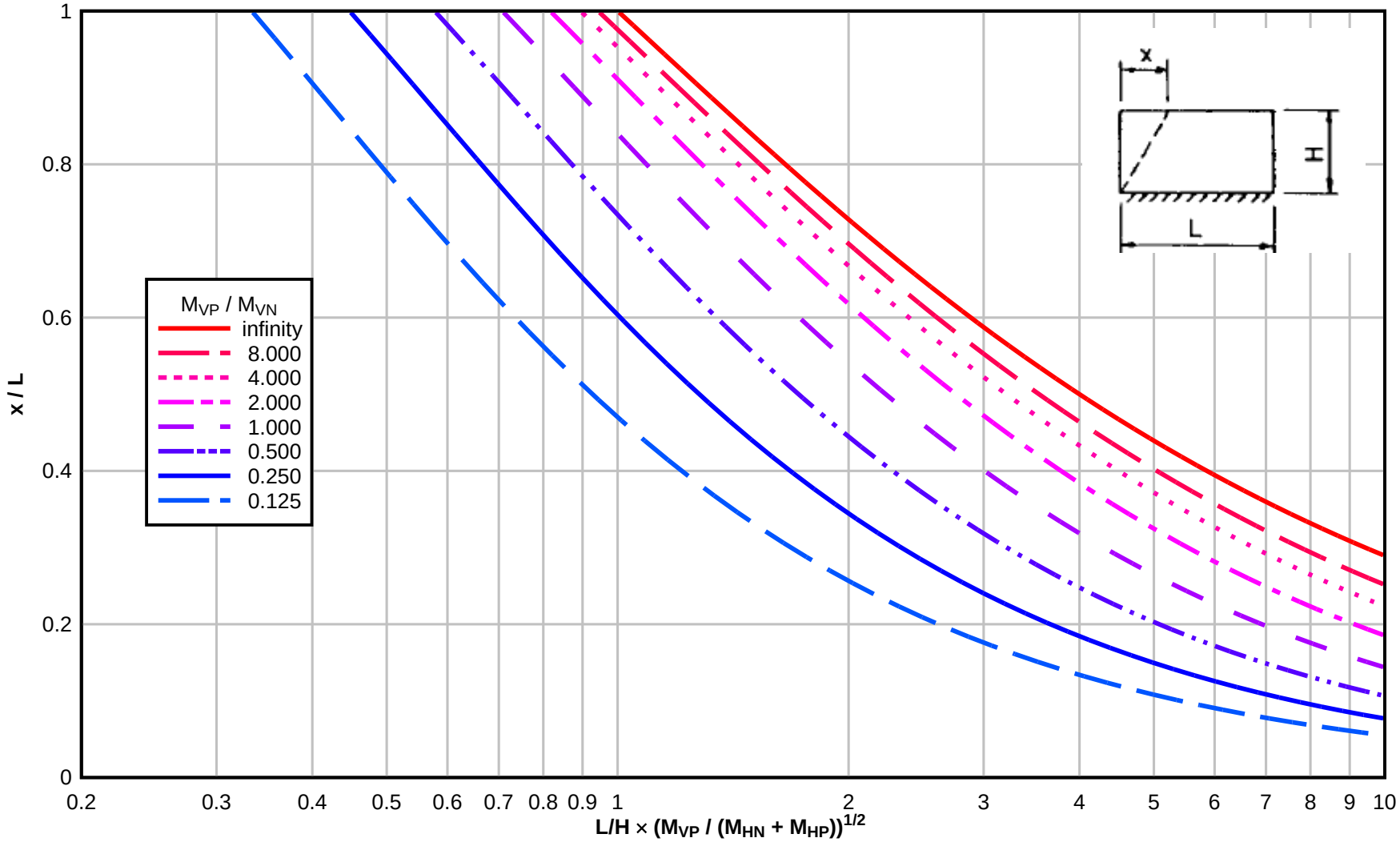


Figure 3-5 Location of Yield Lines for A Two-Way Element with Two Adjacent Edges Supported and Two Edges Free (values of *y*)

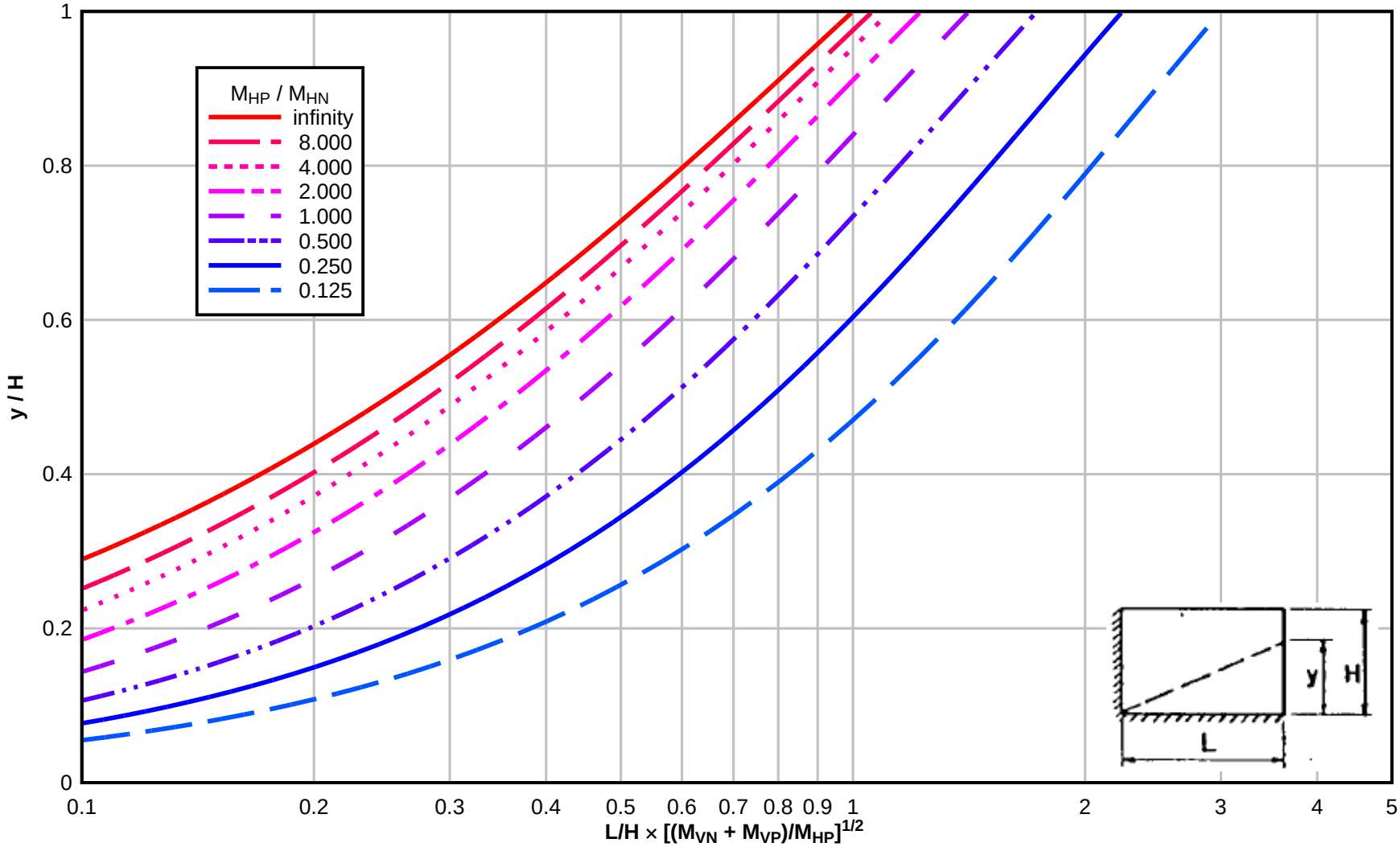


Figure 3-6 Location of Symmetrical Yield Lines for Two-Way Element with Three Edges Supported and One Edge Free

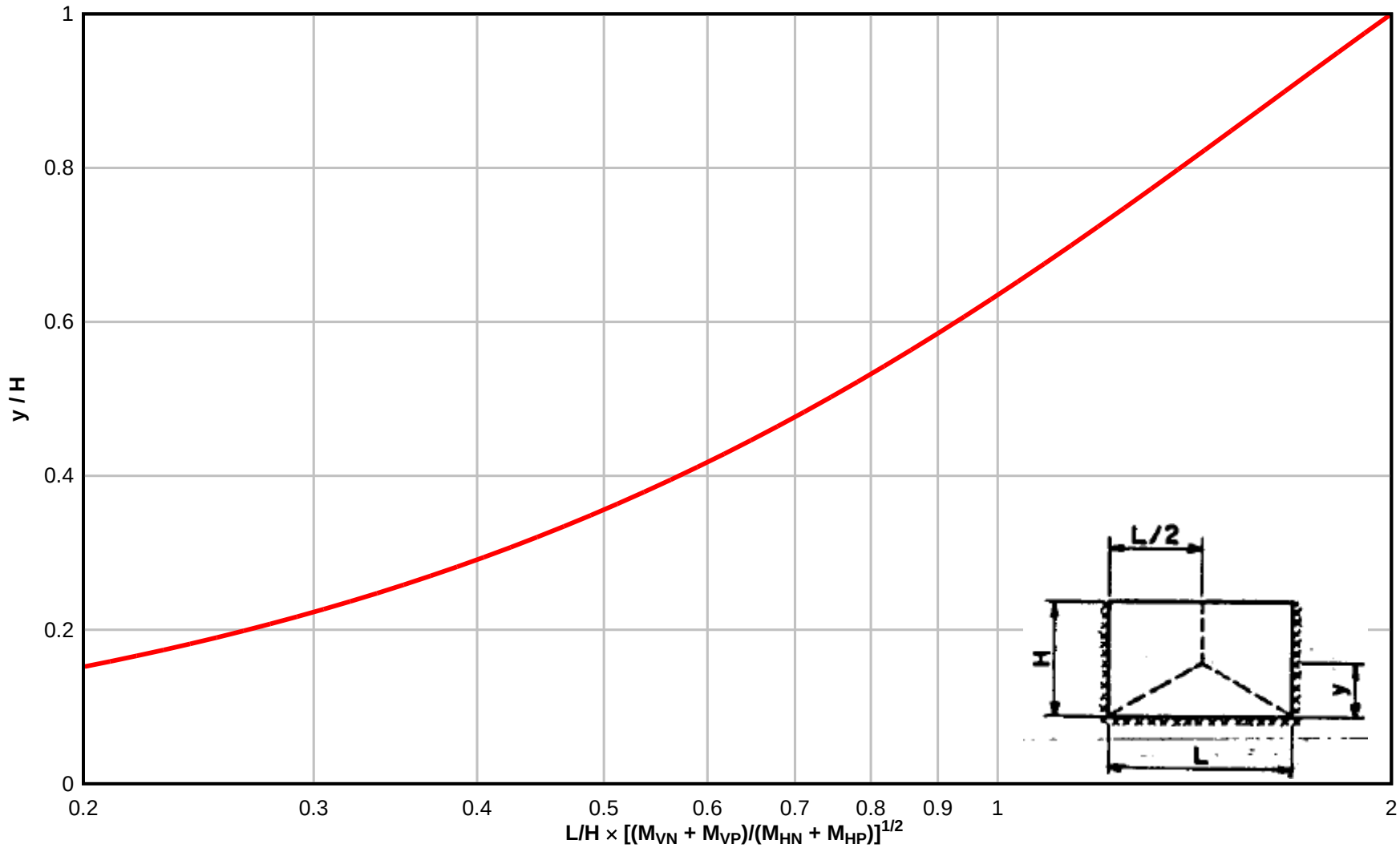


Figure 3-7 Location of Unsymmetrical Yield Lines for A Two-Way Element with Three Edges Supported and One Edge Free (X_2/X_1=0.1)

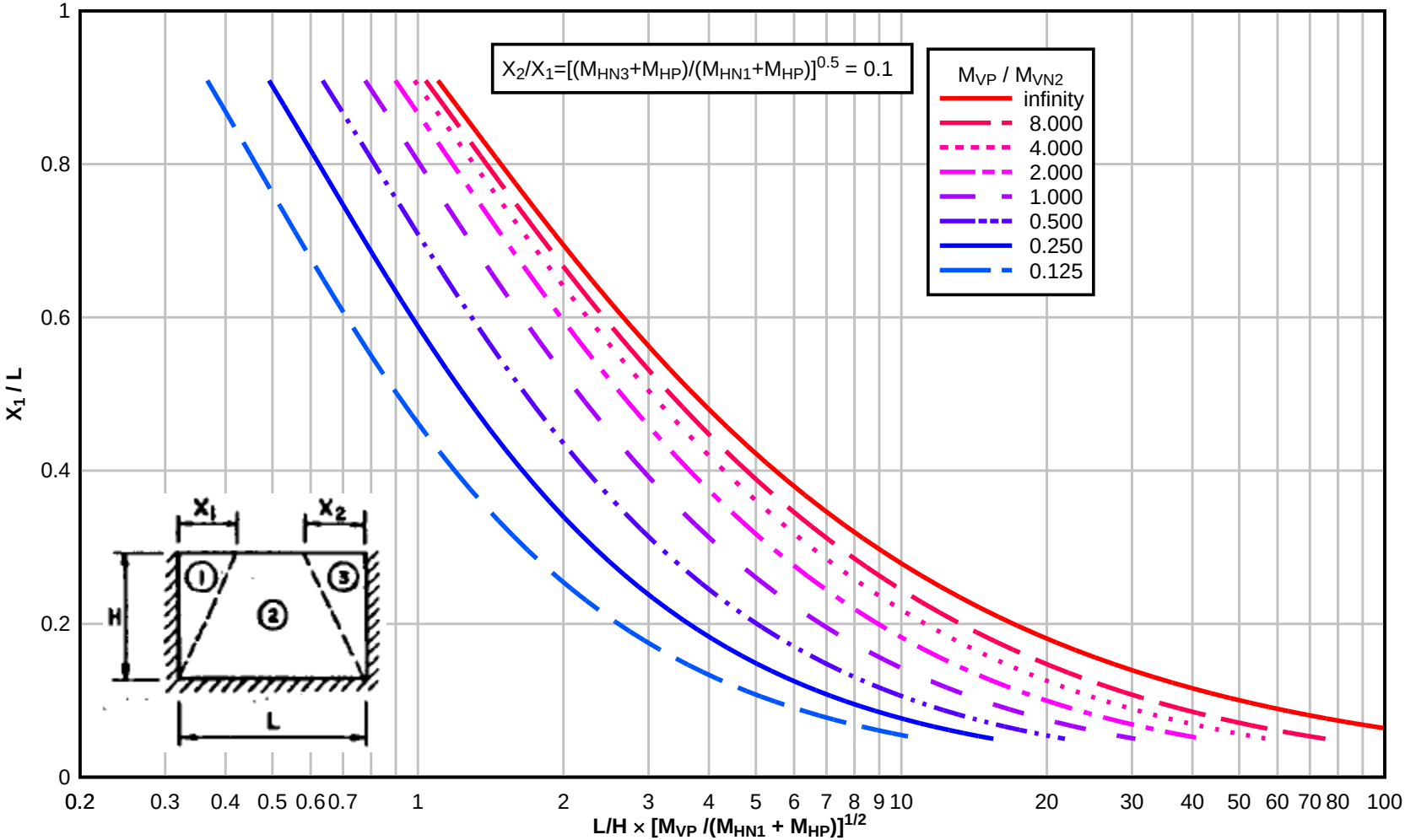


Figure 3-8 Location of Unsymmetrical Yield Lines for Two-Way Element with Three Edges Supported and One Edge Free (X_2/X_1=0.3)

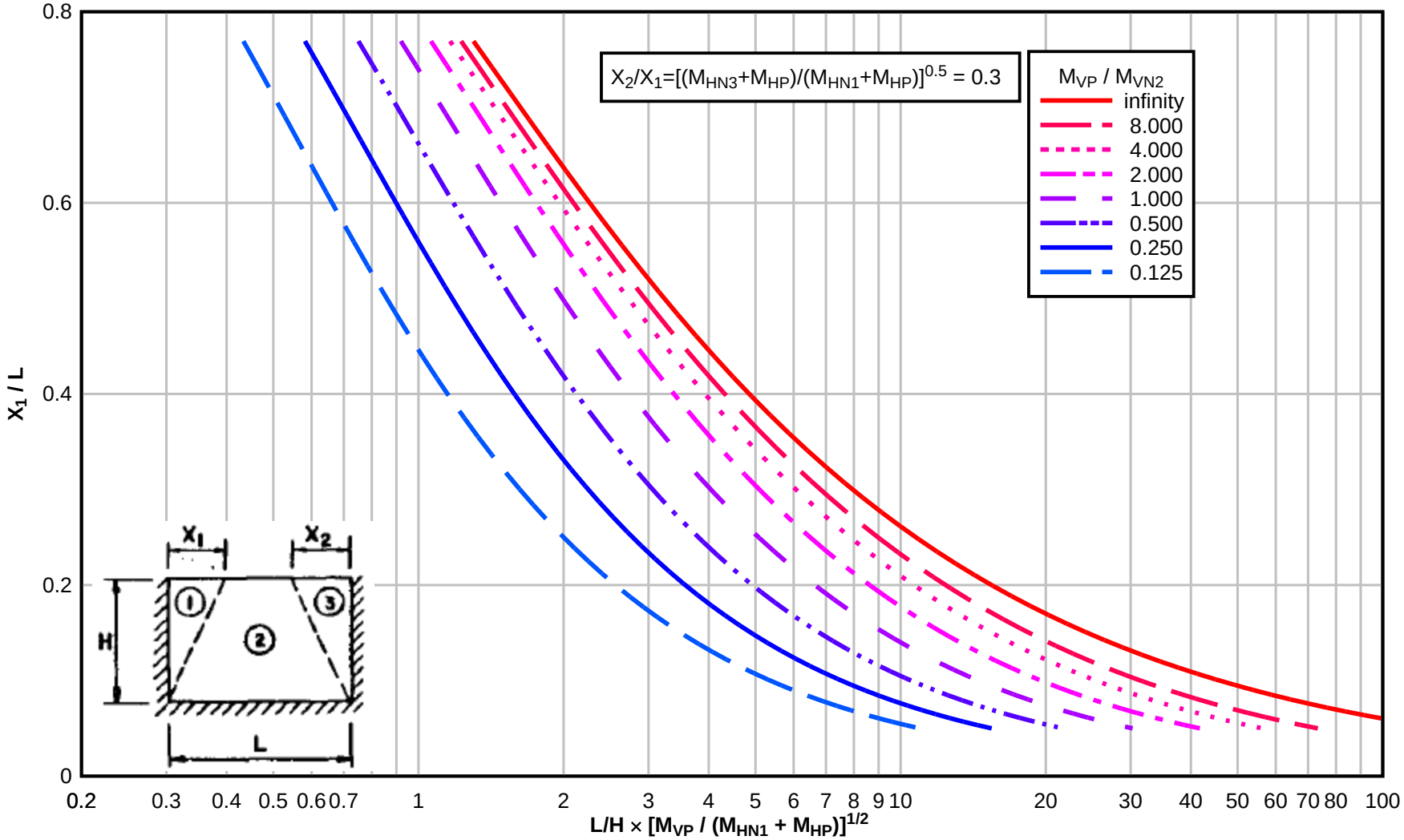


Figure 3-9 Location of Unsymmetrical Yield Lines for Two-Way Element with Three Edges Supported and One Edge Free (X_2/X_1=0.5)

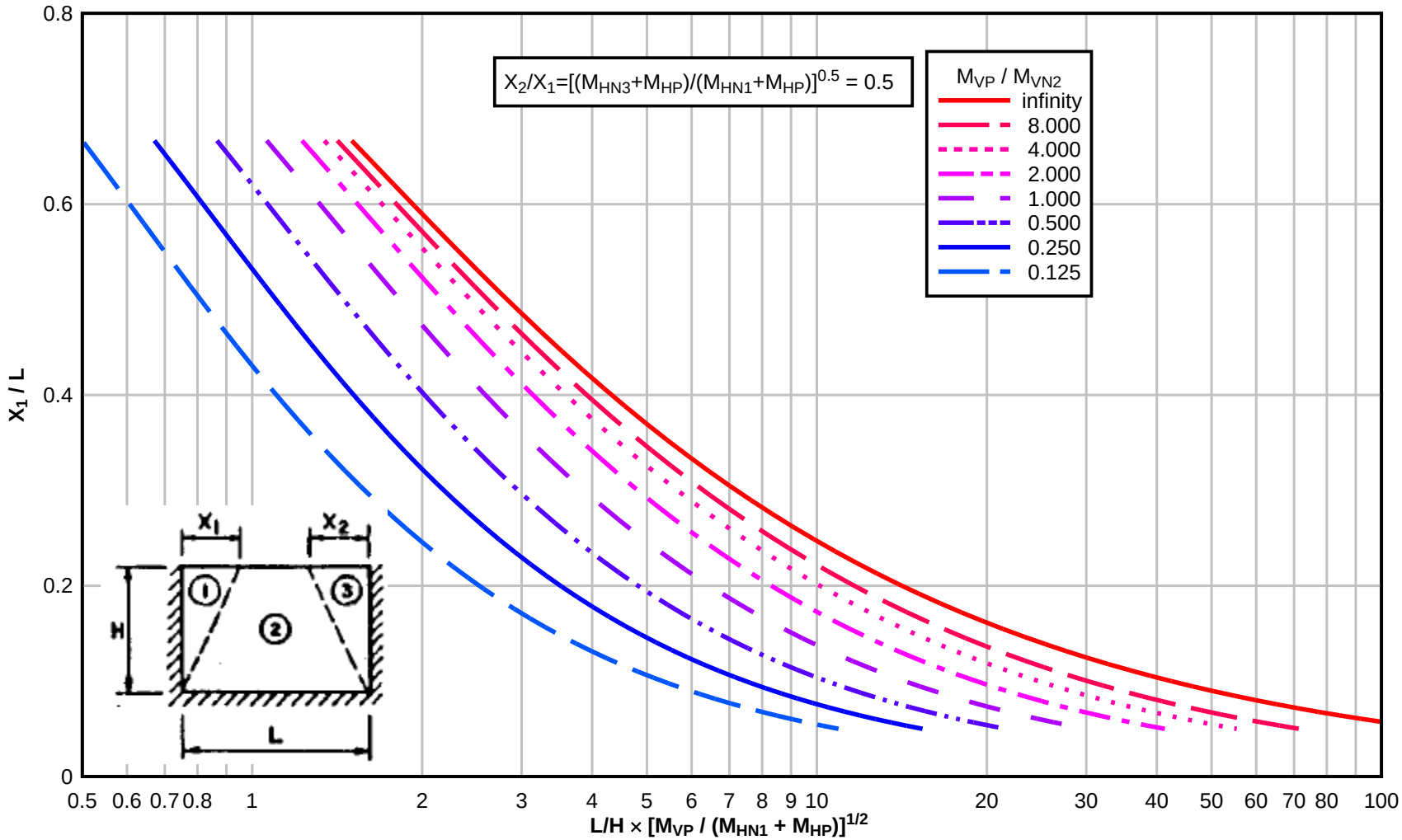


Figure 3-10 Location of Unsymmetrical Yield Lines for Two-Way Element with Three Edges Supported and One Edge Free (X_2/X_1=0.75)

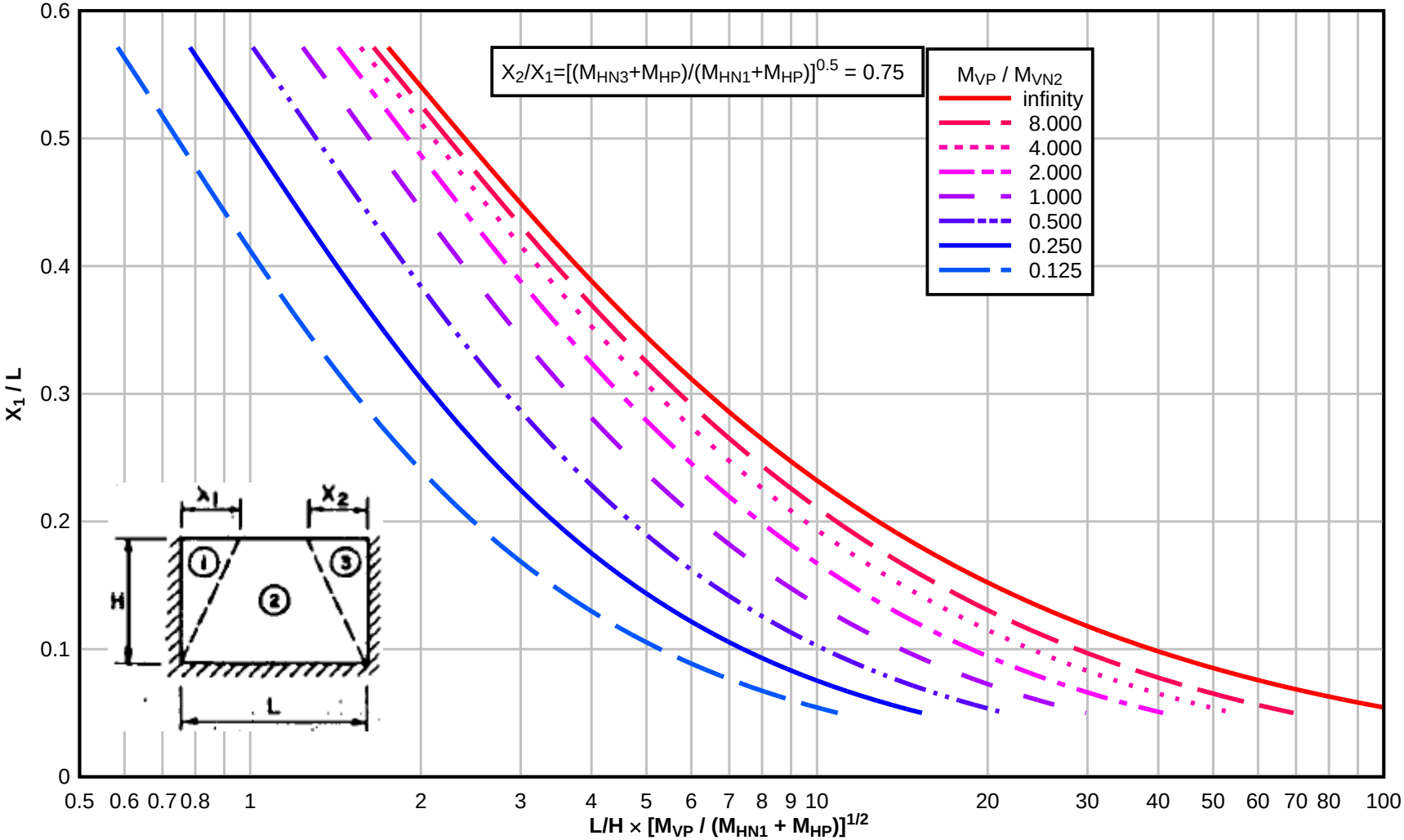


Figure 3-11 Location of Symmetrical Yield Lines for Two-Way Element with Three Edges Supported and One Edge Free (X_2/X_1=1.0)

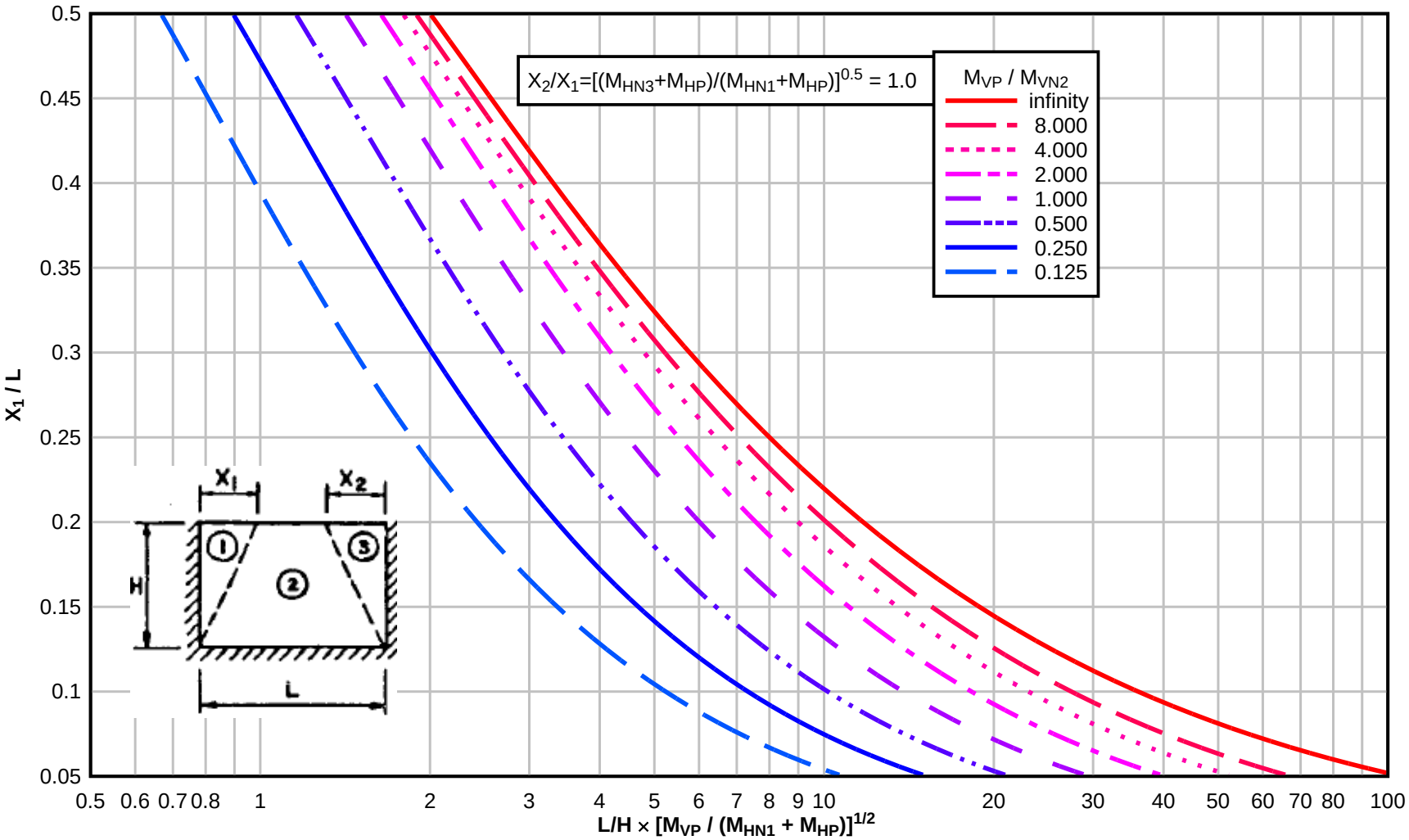


Figure 3-12 Location of Unsymmetrical Yield Lines for Two-Way Element with Three Edges Supported and One Edge Free (X_2/X_1=1.25)

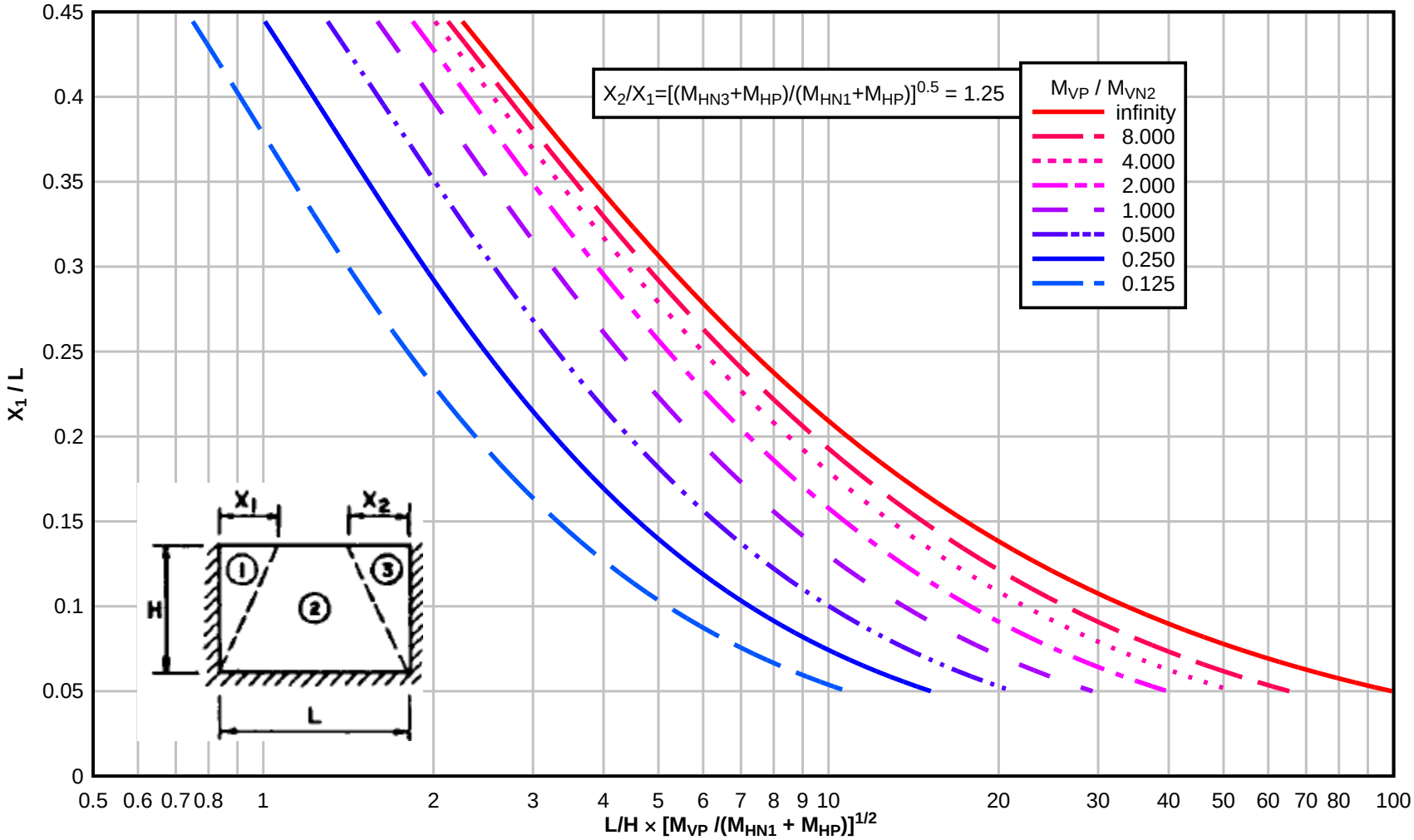


Figure 3-13 Location of Unsymmetrical Yield Lines for Two-Way Element with Three Edges Supported and One Edge Free (X_2/X_1=1.5)

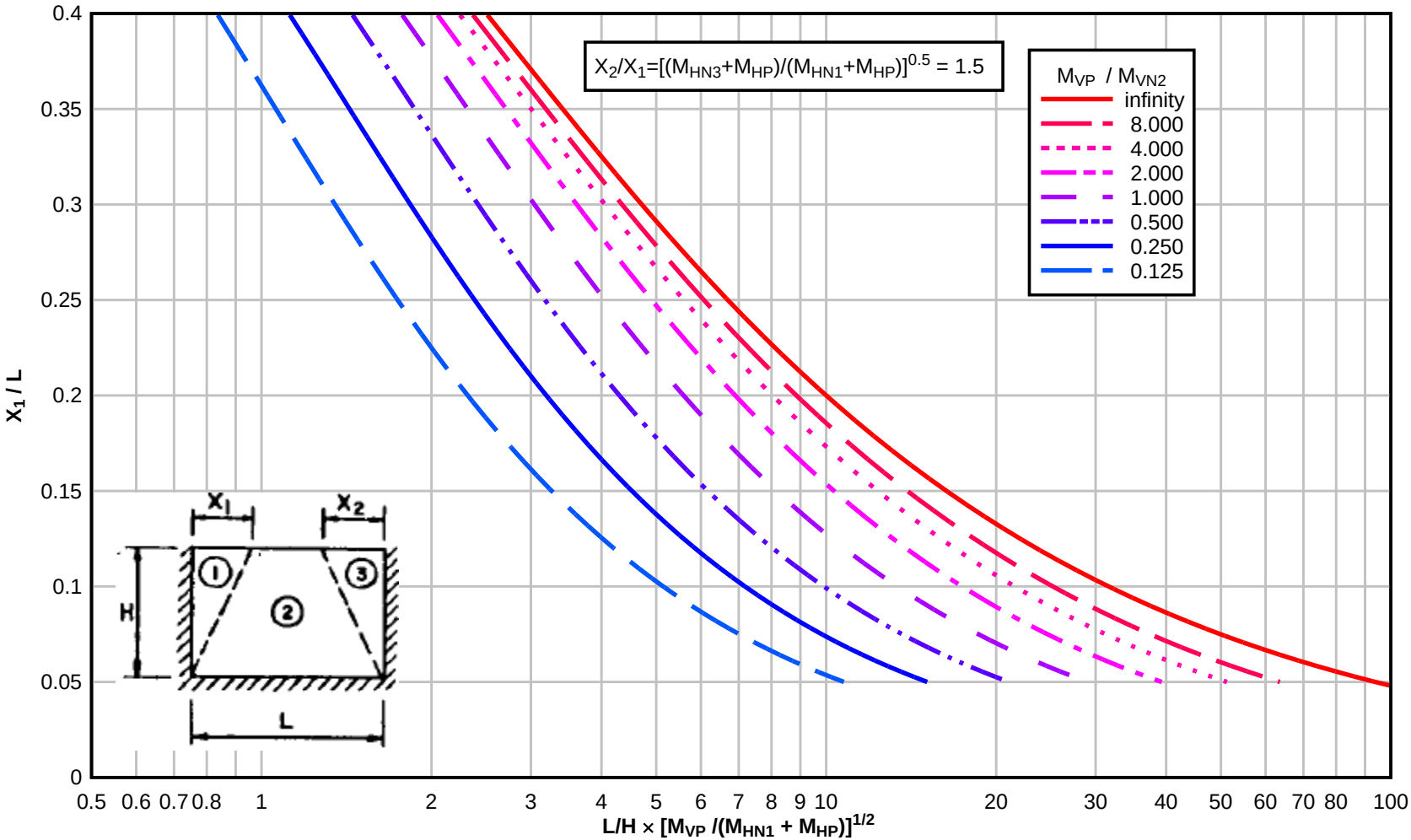


Figure 3-14 Location of Unsymmetrical Yield Lines for Two-Way Element with Three Edges Supported and One Edge Free (X_2/X_1=1.75)

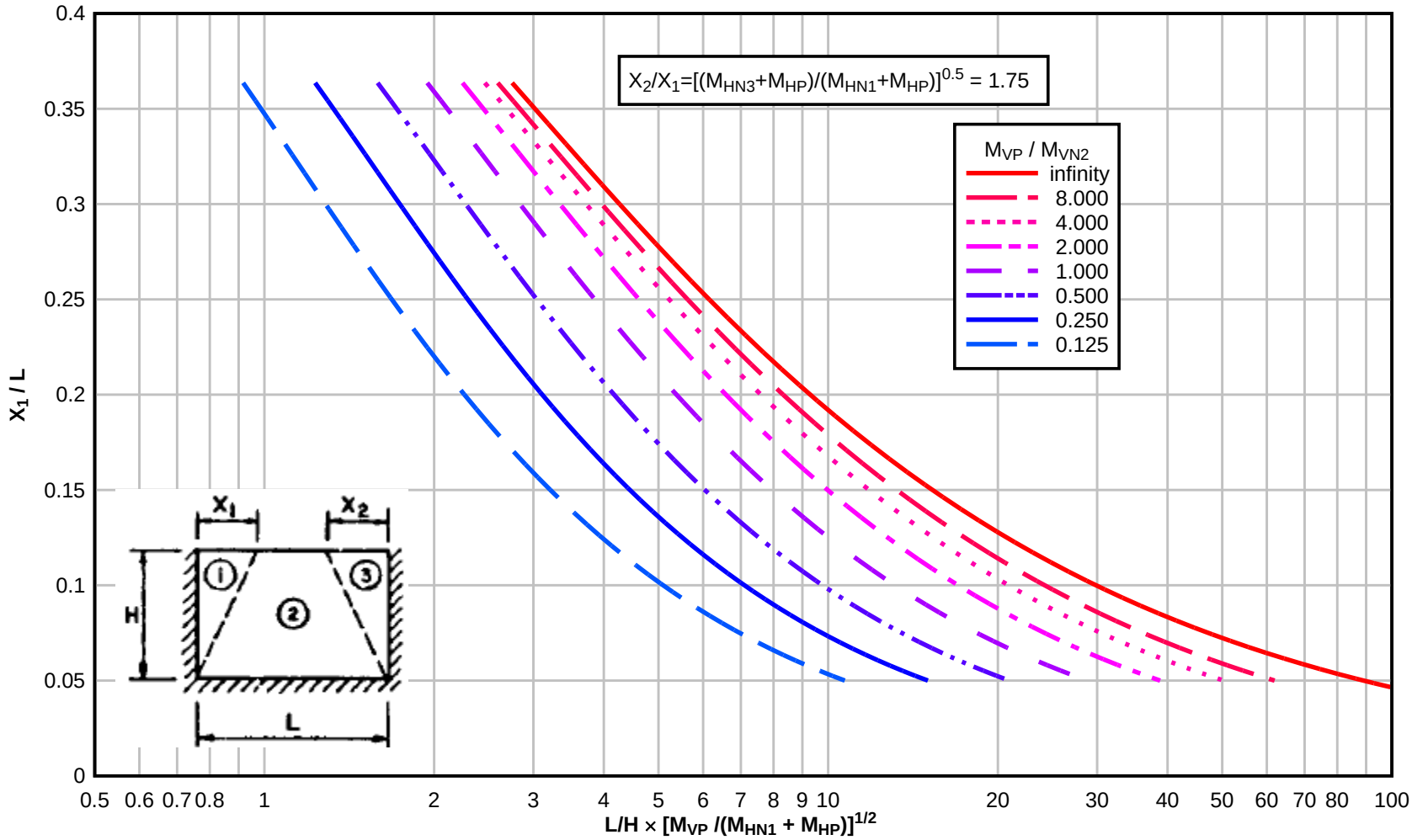


Figure 3-15 Location of Unsymmetrical Yield Lines for Two-Way Element with Three Edges Supported and One Edge Free (X_2/X_1=2.0)

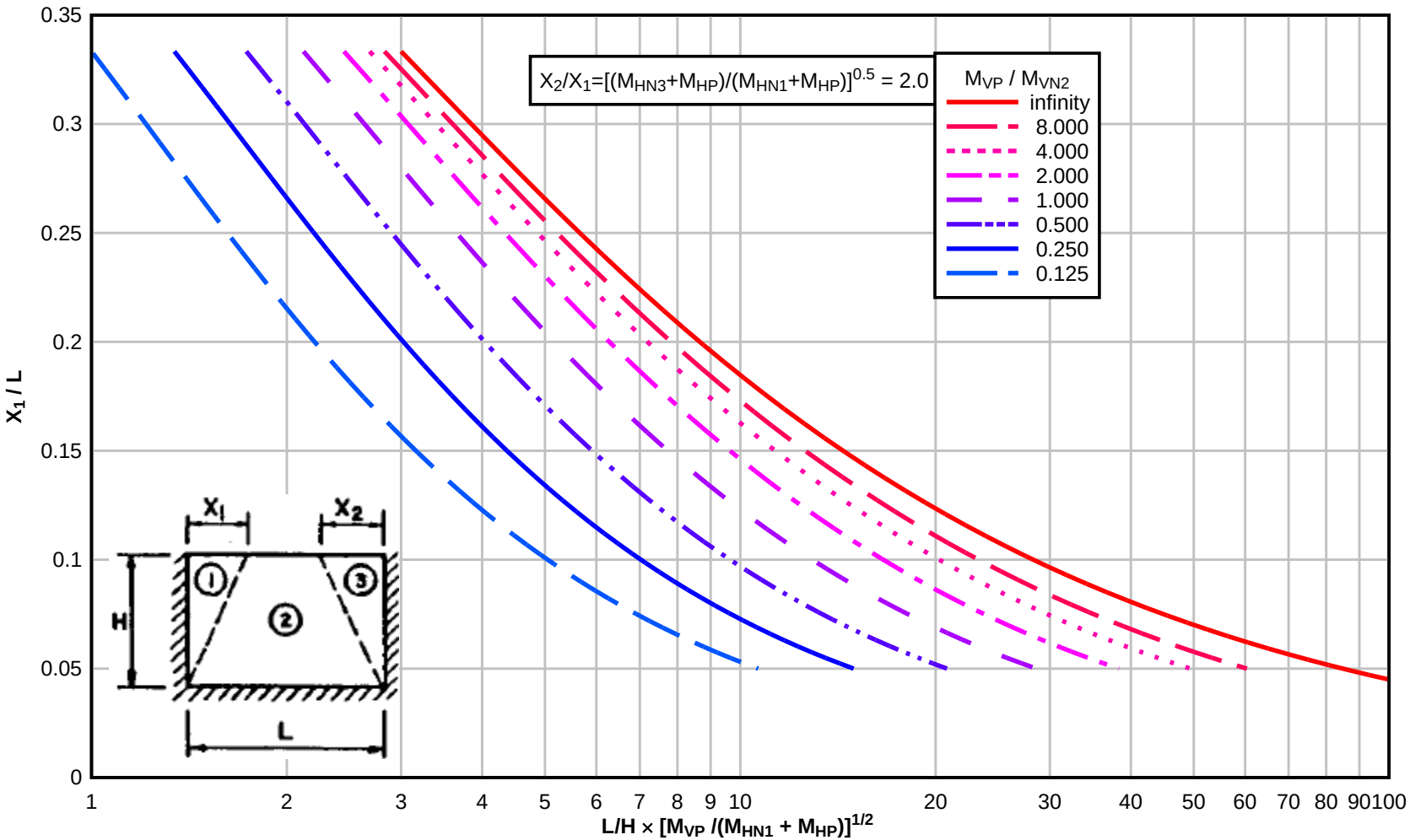


Figure 3-16 Location of Unsymmetrical Yield Lines for Two-Way Element with Three Edges Supported and One Edge Free (Values of *y*)

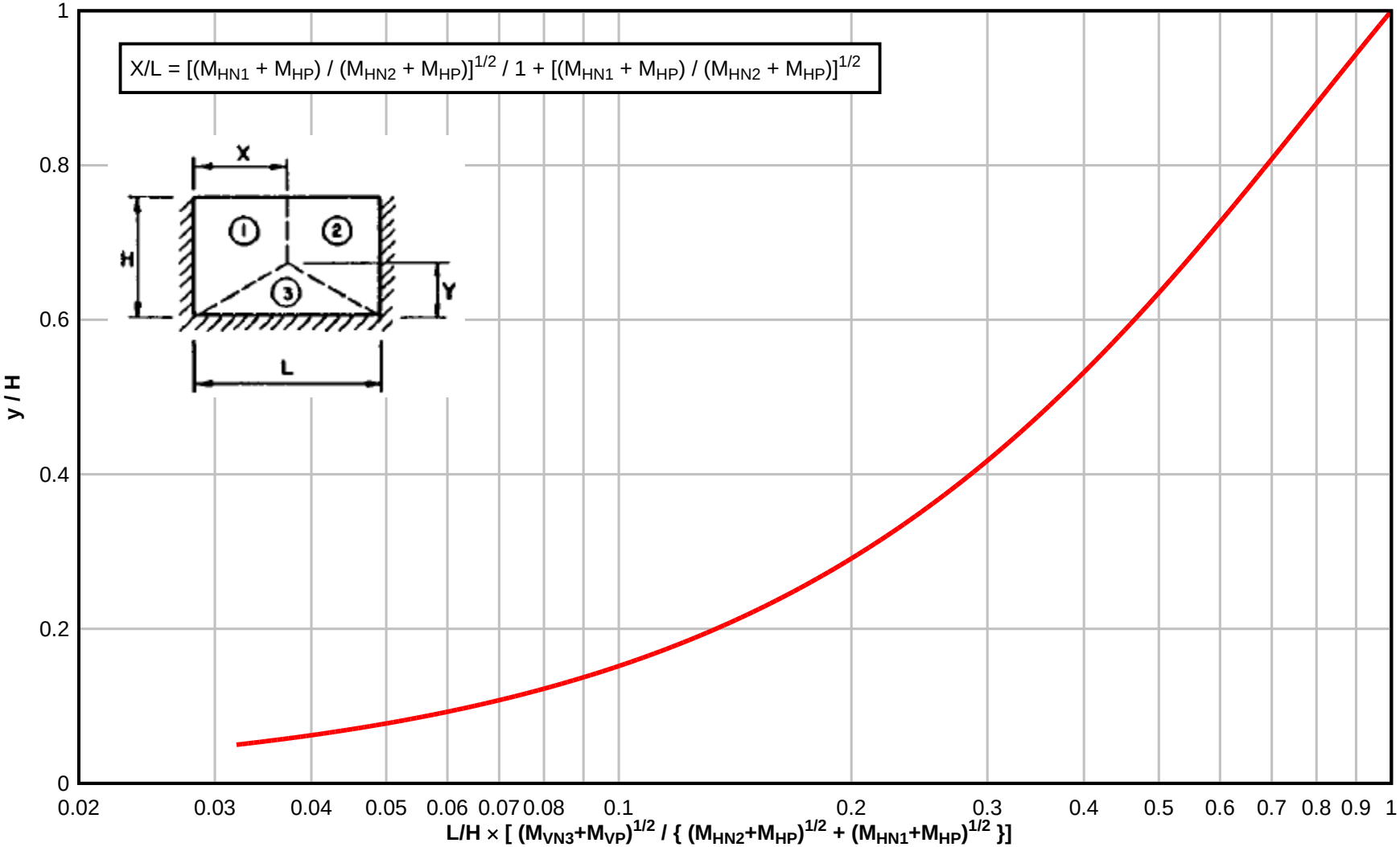


Figure 3-17 Location of Symmetrical Yield Lines for Two-Way Element with Four Edges Supported

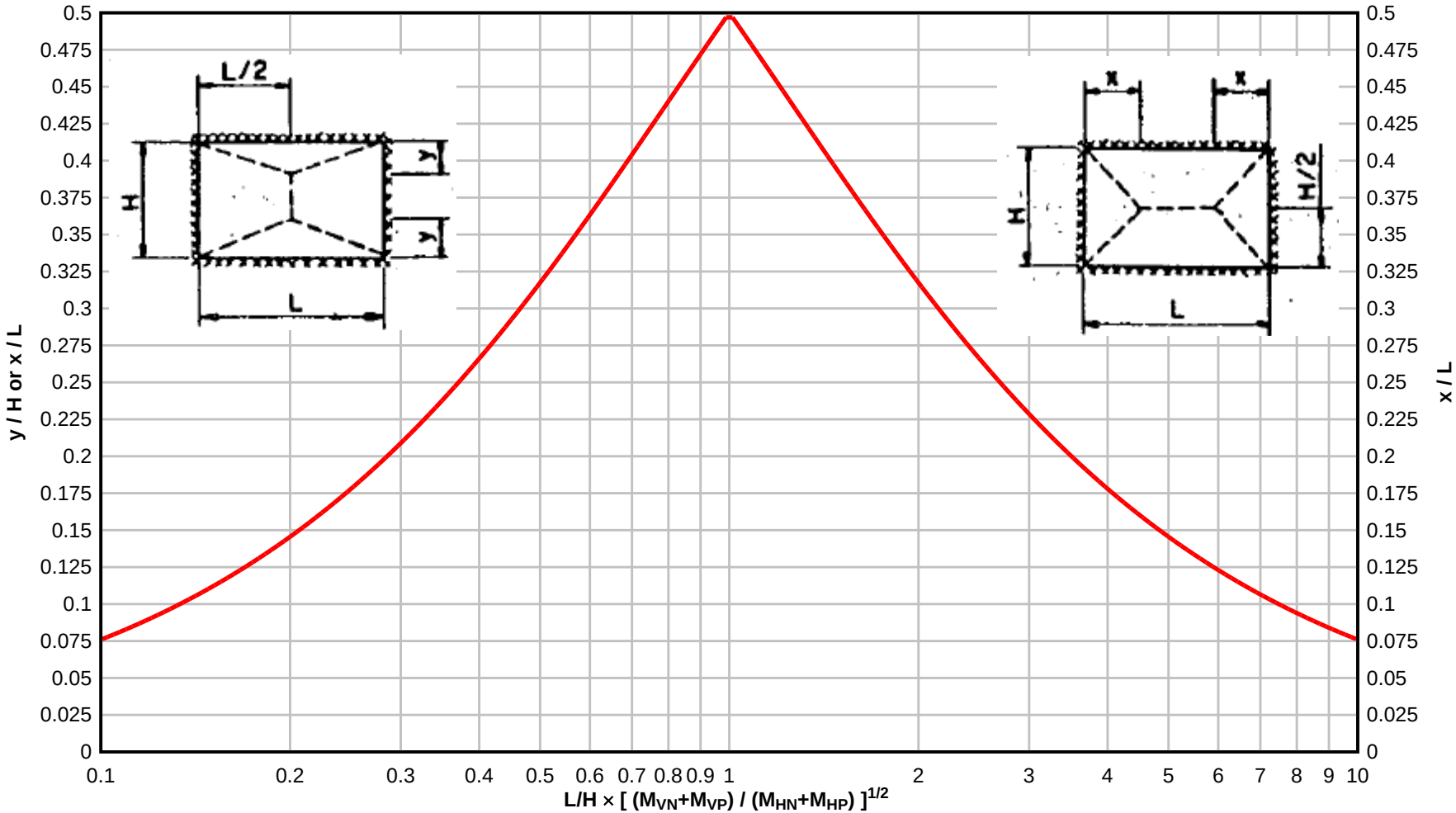


Figure 3-18 Location of Unsymmetrical Yield Lines for Two-Way Element With Four Edges Supported (Values of x_1)

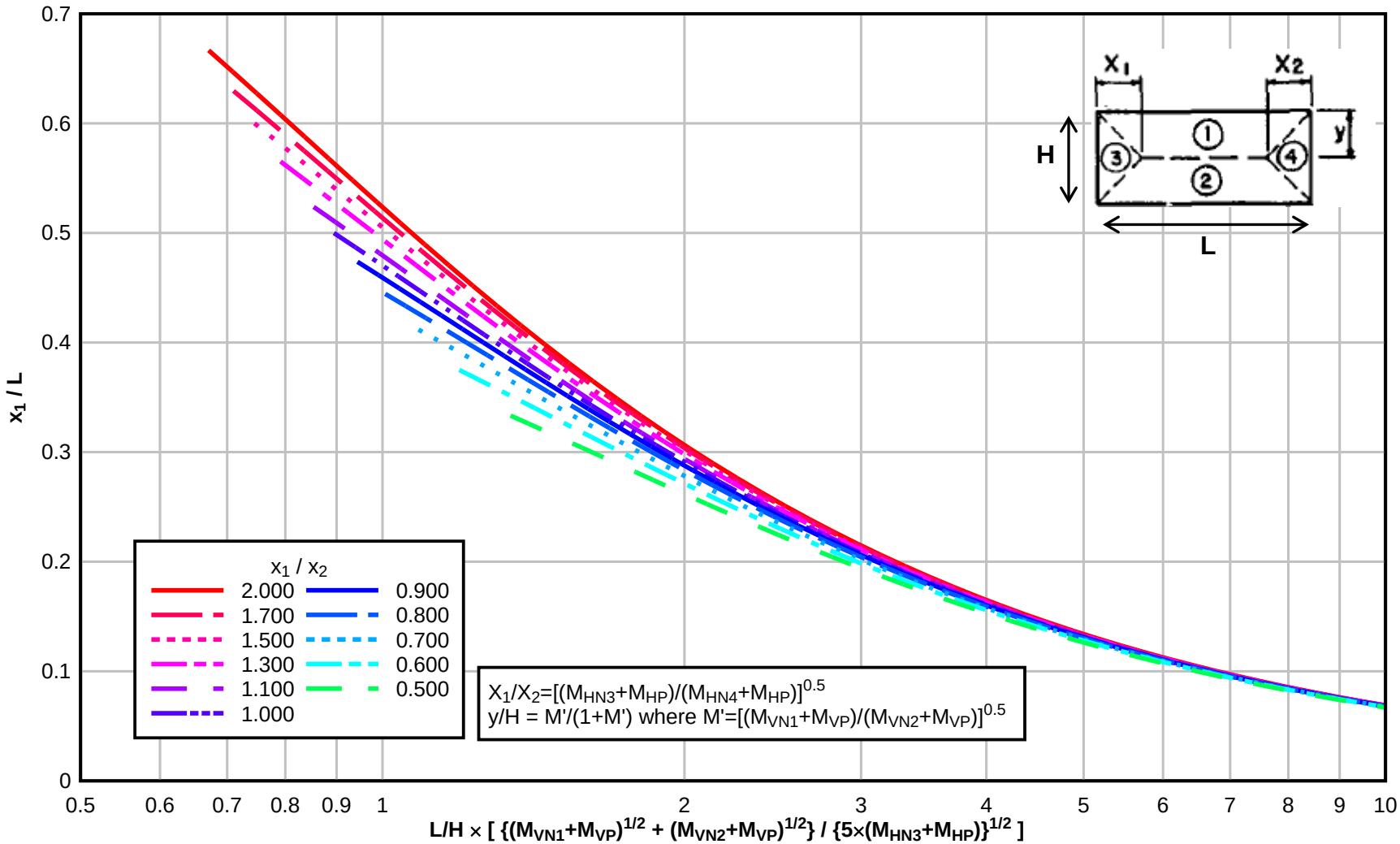


Figure 3-19 Location of Unsymmetrical Yield Lines for Two-Way Element with Four Edges Supported (Values of y_1)

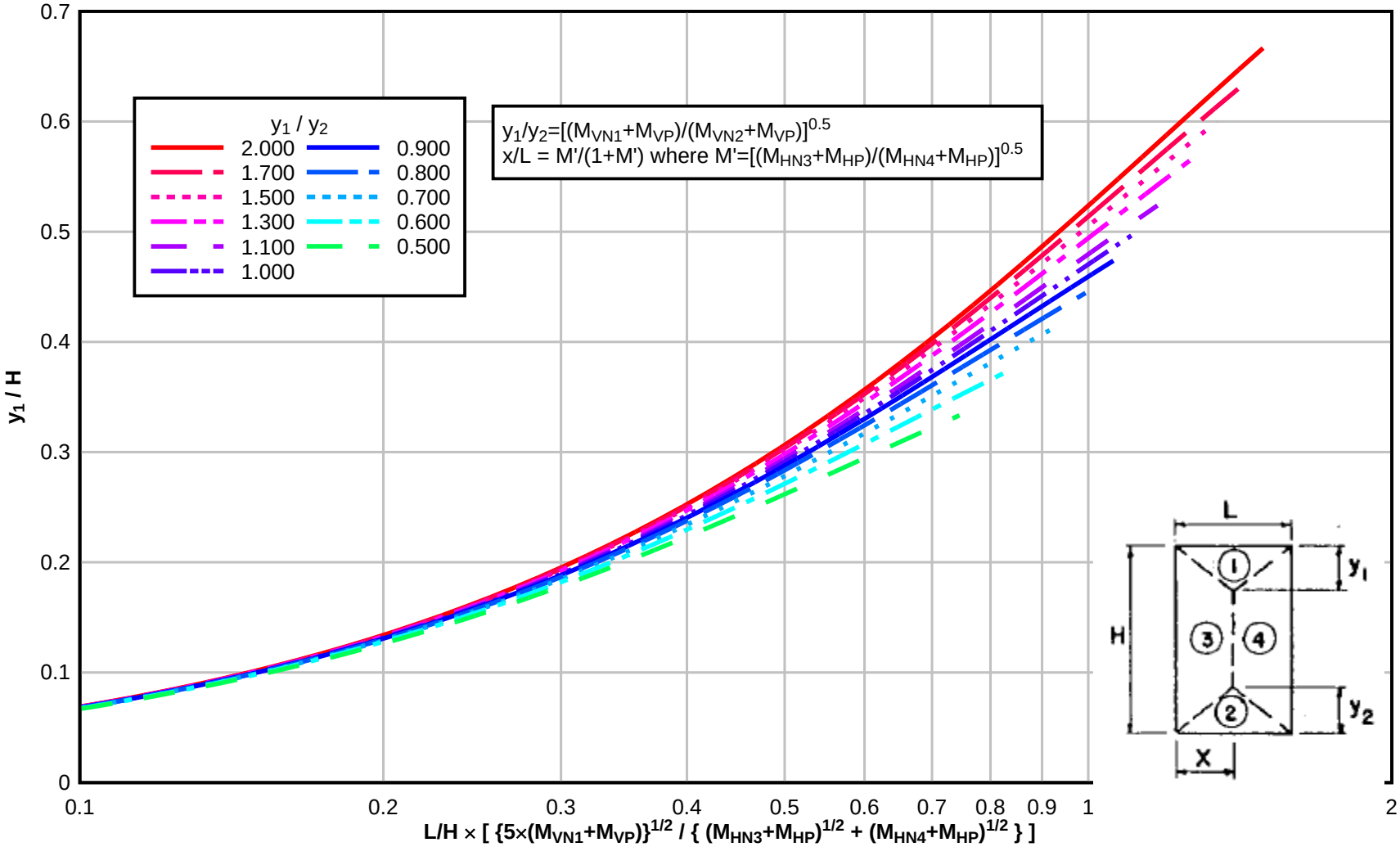


Figure 3-20 Location of Unsymmetrical Yield Lines for Two-Way Element with Four Edges Supported (Values of *x*/*L* and *y*/*H*)

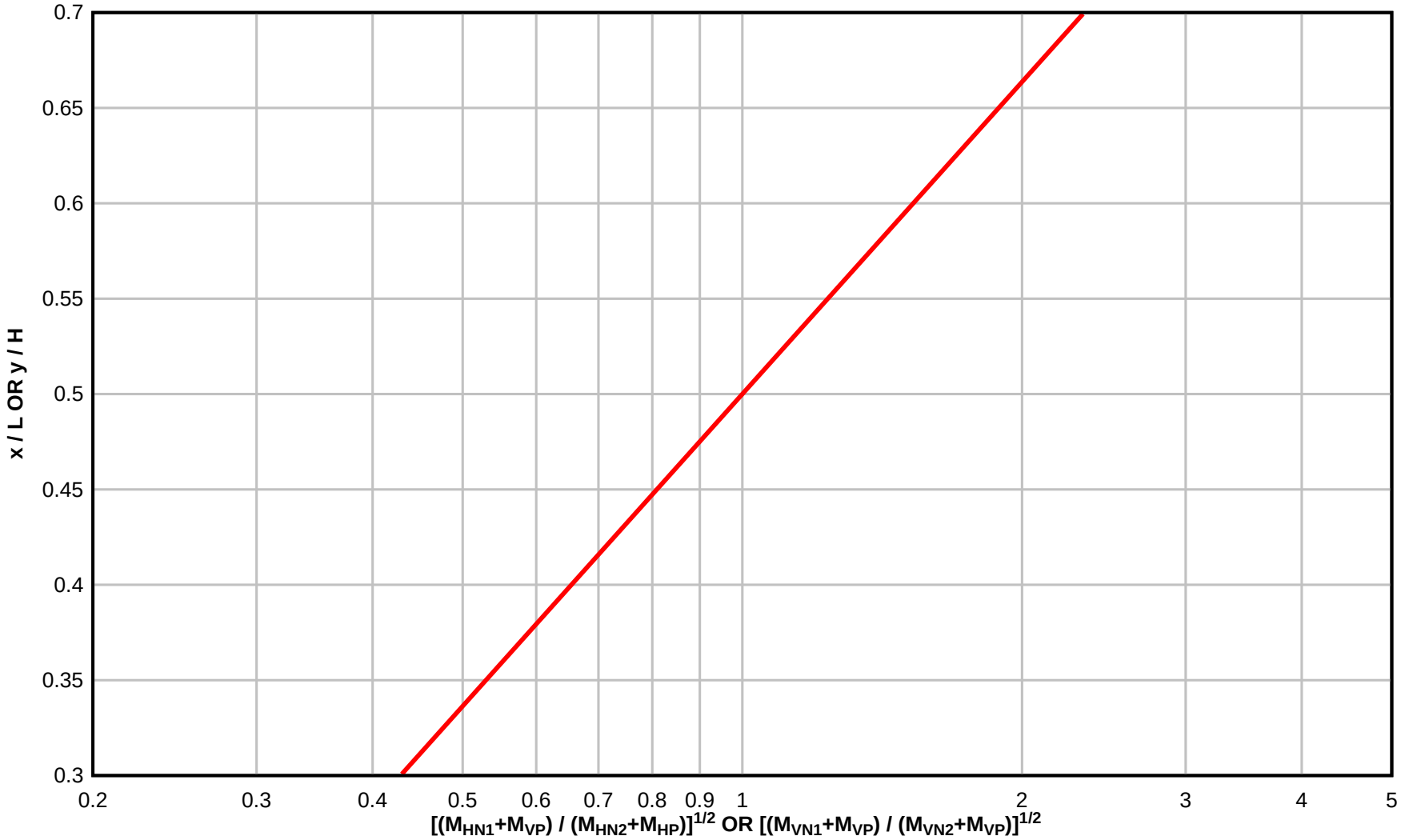


Figure 3-21 Effects of Openings on Yield Line Locations

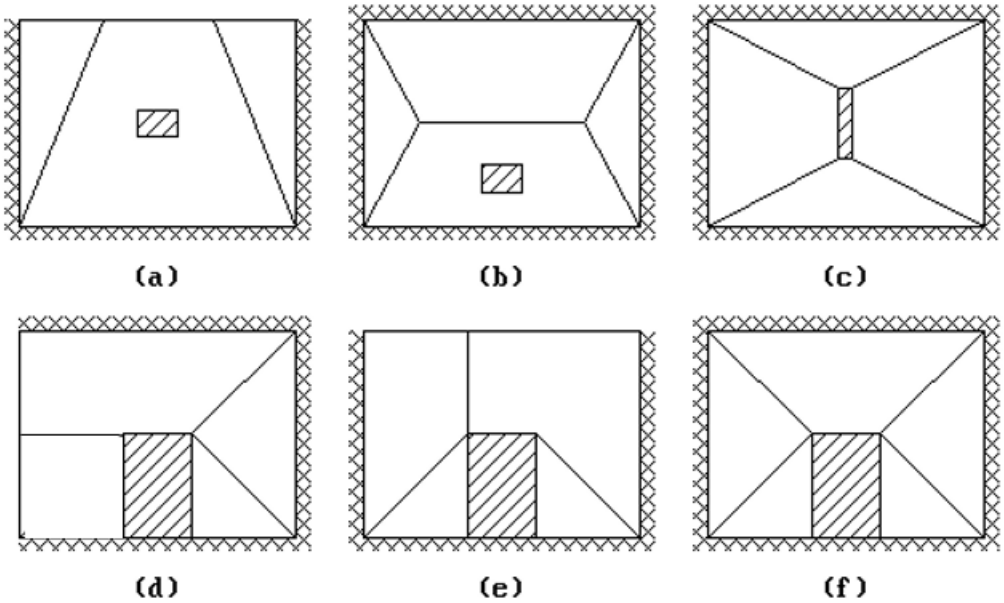


Figure 3-22 Deflection of Two-Way Element

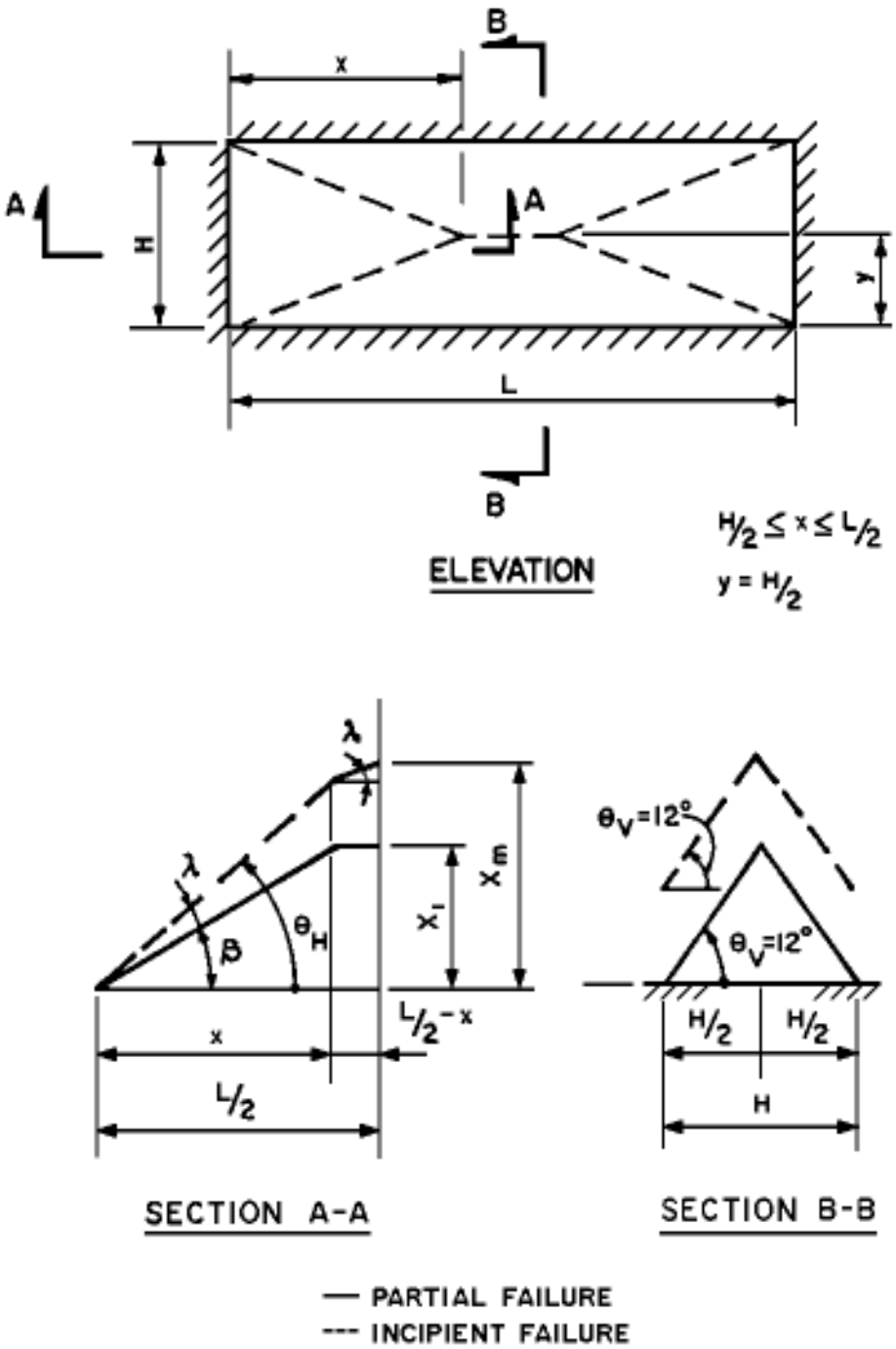


Figure 3-23 Graphical Summary of Two-Way Elements

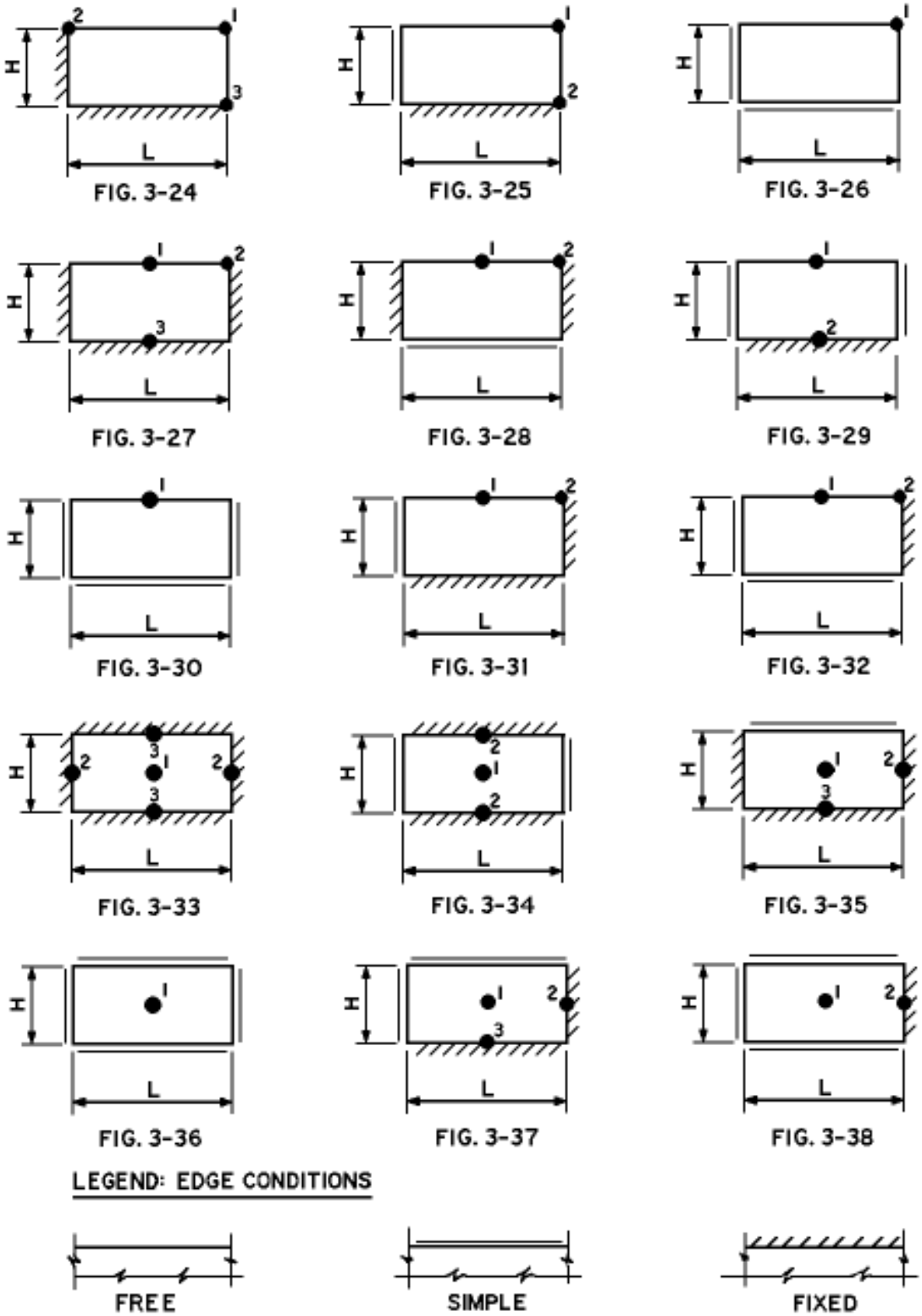


Figure 3-24 Moment and Deflection Coefficients for Uniformly-Loaded, Two-Way Element with Two Adjacent Edges Fixed and Two Edges Free

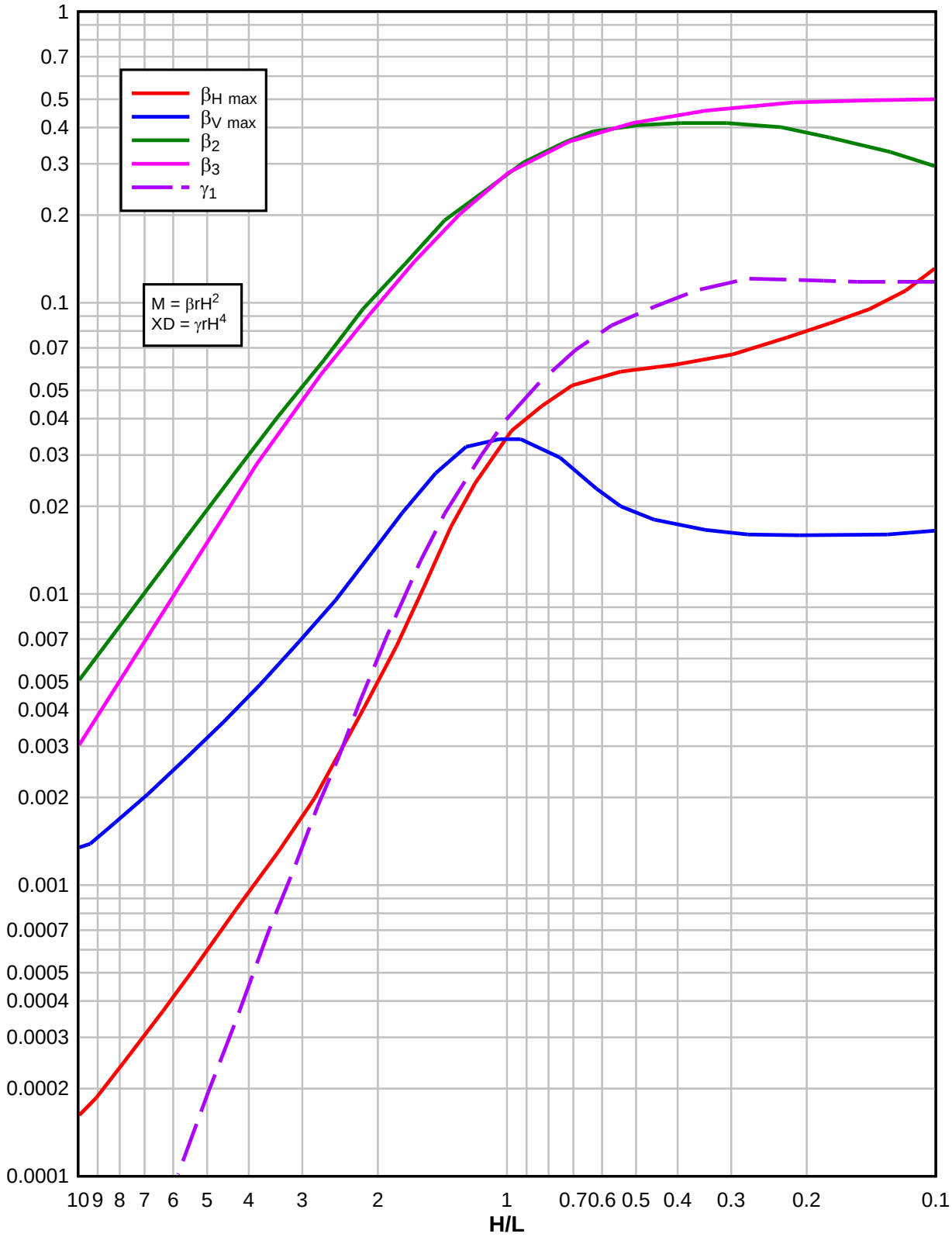


Figure 3-25 Moment and Deflection Coefficients for Uniformly-Loaded, Two-Way Element with One Edge Fixed, an Adjacent Edge Simply-Supported and Two Edges Free.

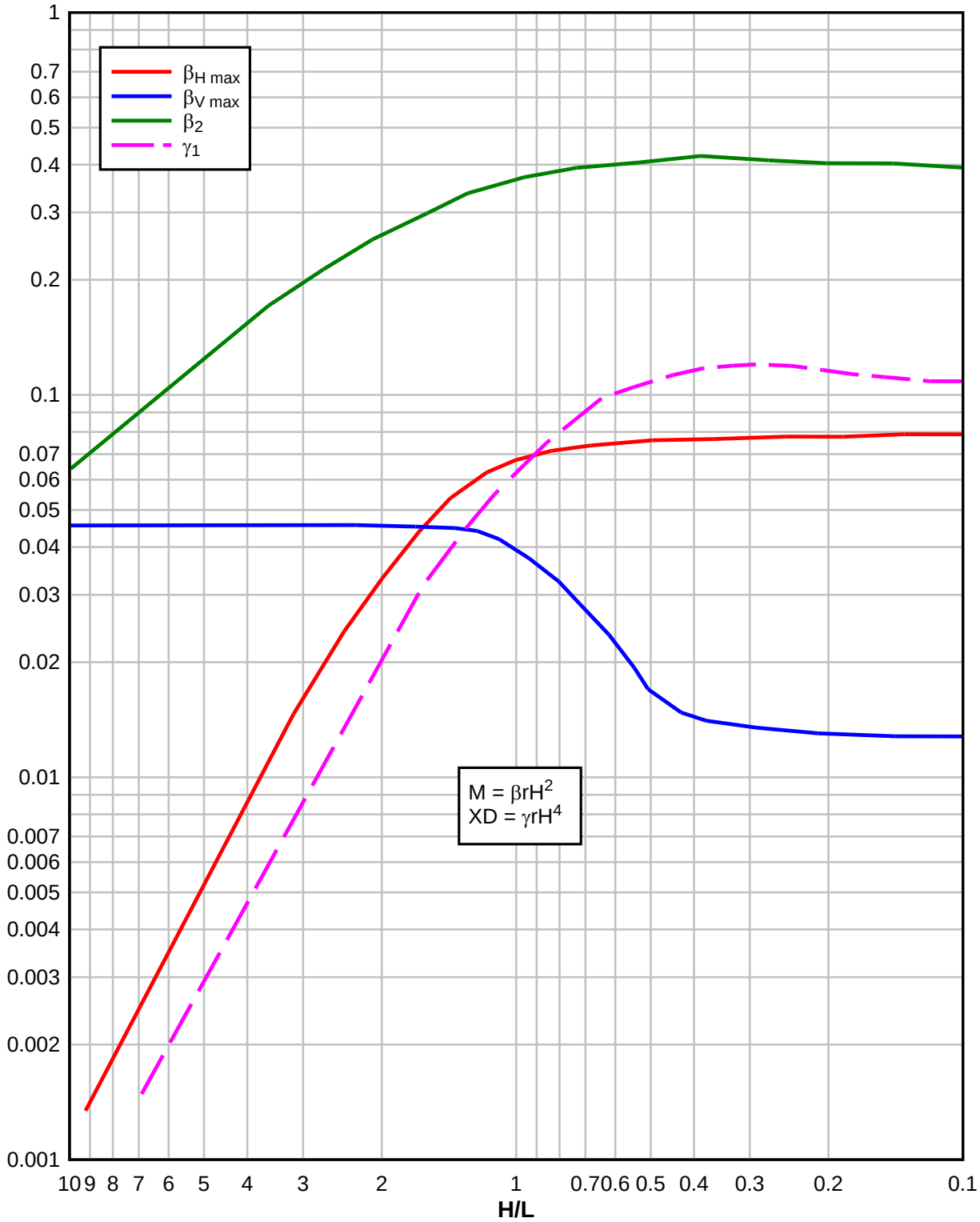


Figure 3-26 Moment and Deflection Coefficients for Uniformly-Loaded, Two-Way Element with Two Adjacent Edges Simply-Supported and Two Edges Free

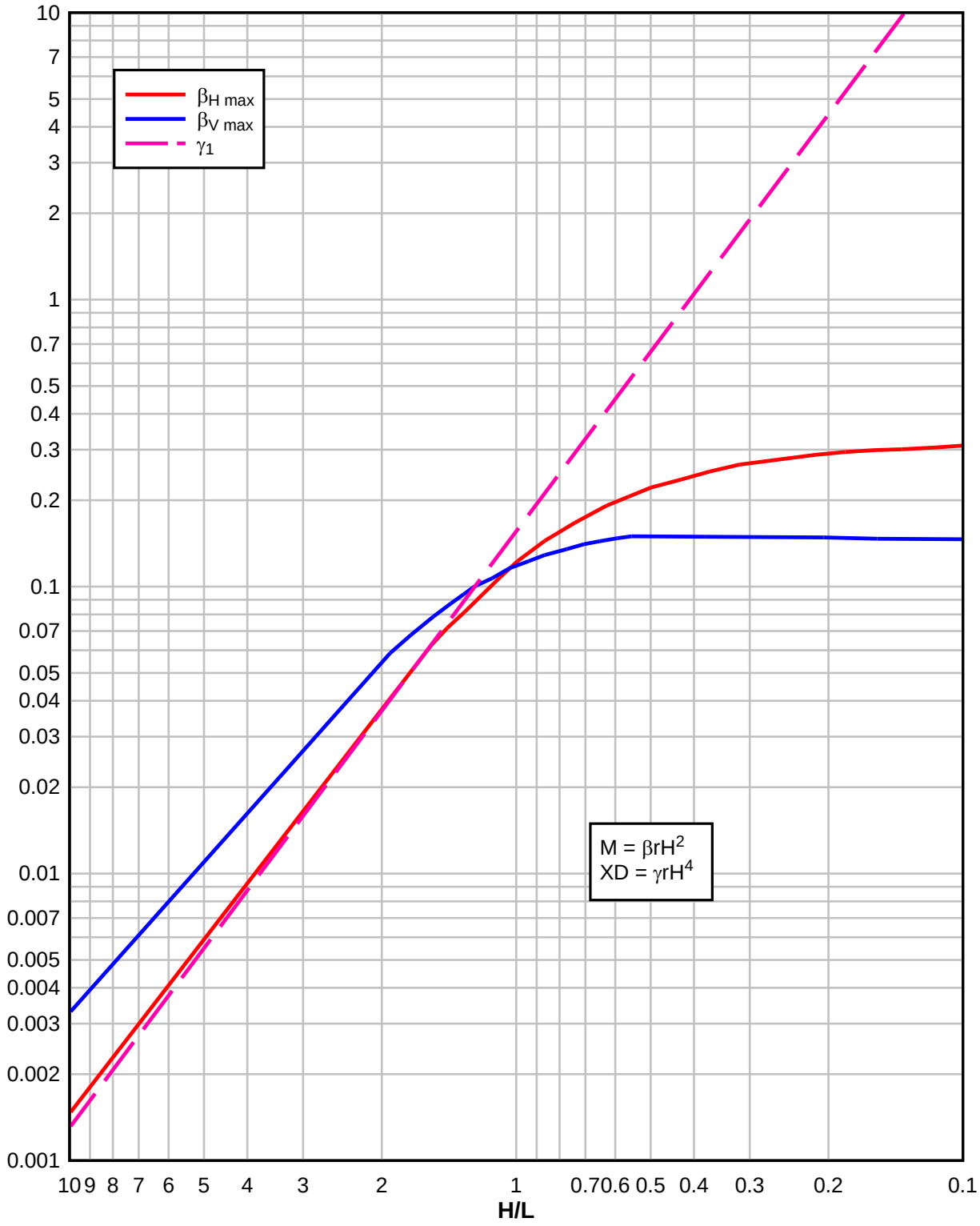


Figure 3-27 Moment and Deflection Coefficients for Uniformly-Loaded, Two-Way Element with Three Edges Fixed and One Edge Free

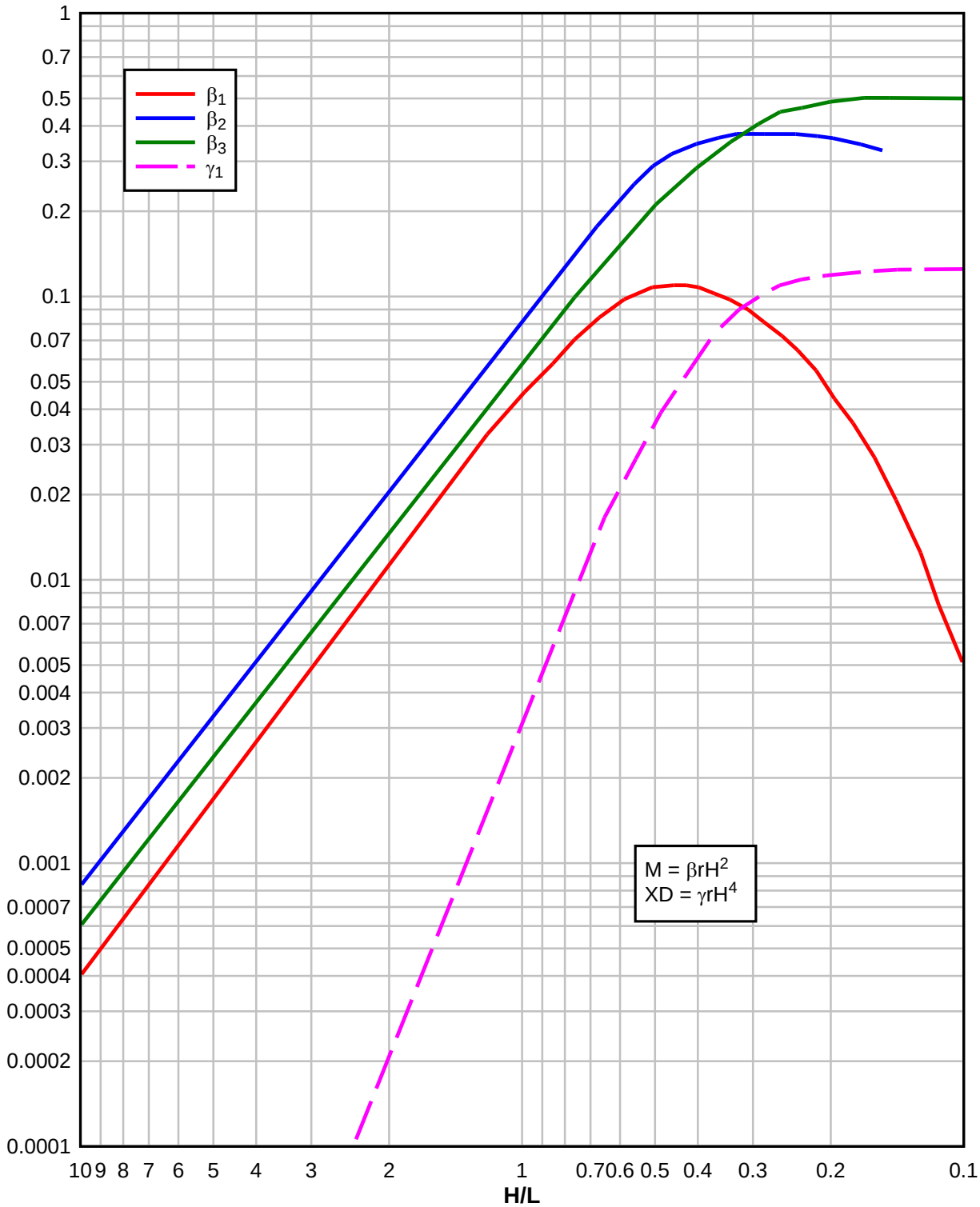


Figure 3-28 Moment and Deflection Coefficients for Uniformly-Loaded, Two-Way Element with Two Opposite Edges Fixed, One Edge Simply-Supported and One Edge Free

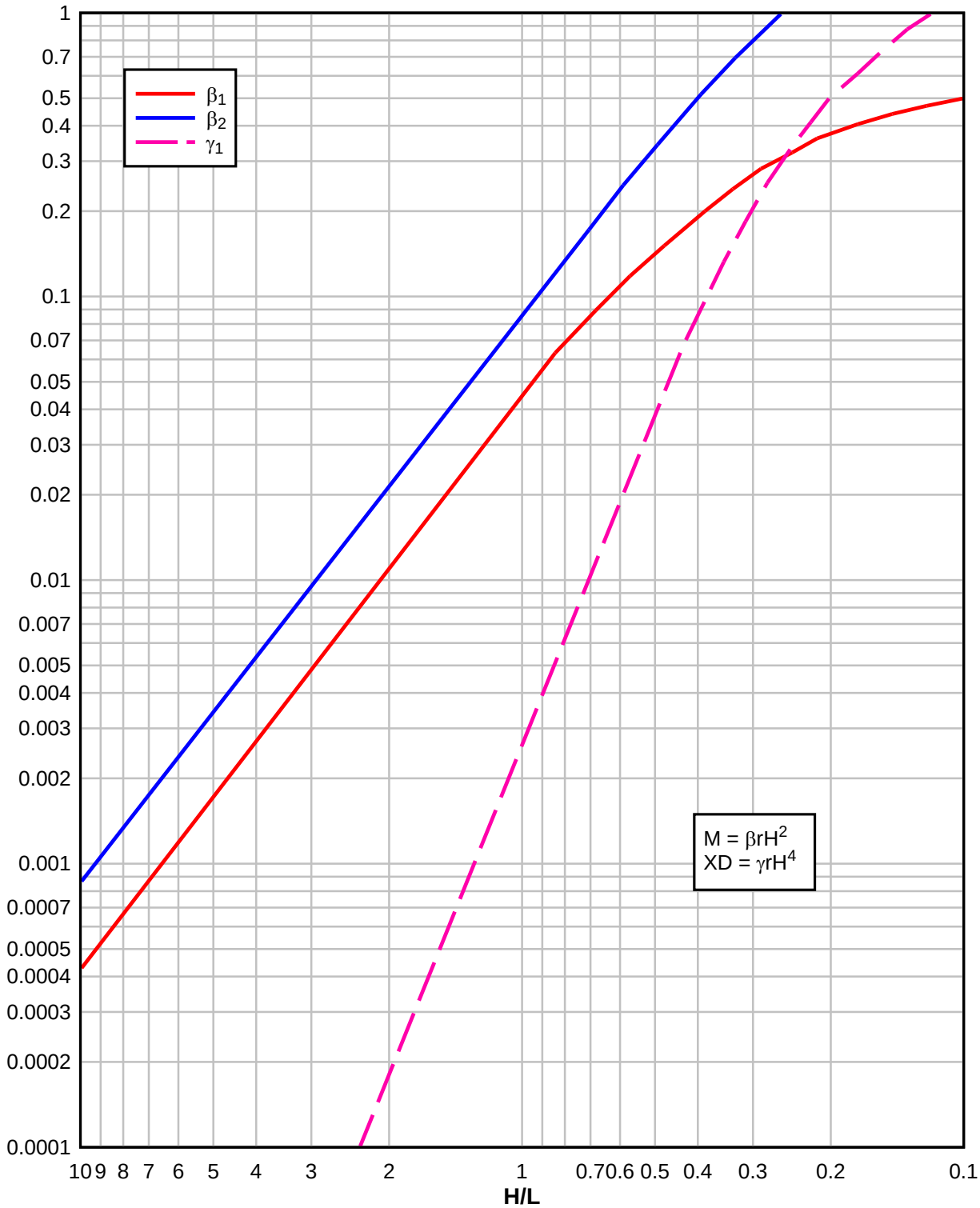


Figure 3-29 Moment and Deflection Coefficients for Uniformly-Loaded, Two-Way Element with Two Opposite Edges Simply-Supported, One Edge Fixed, and One Edge Free

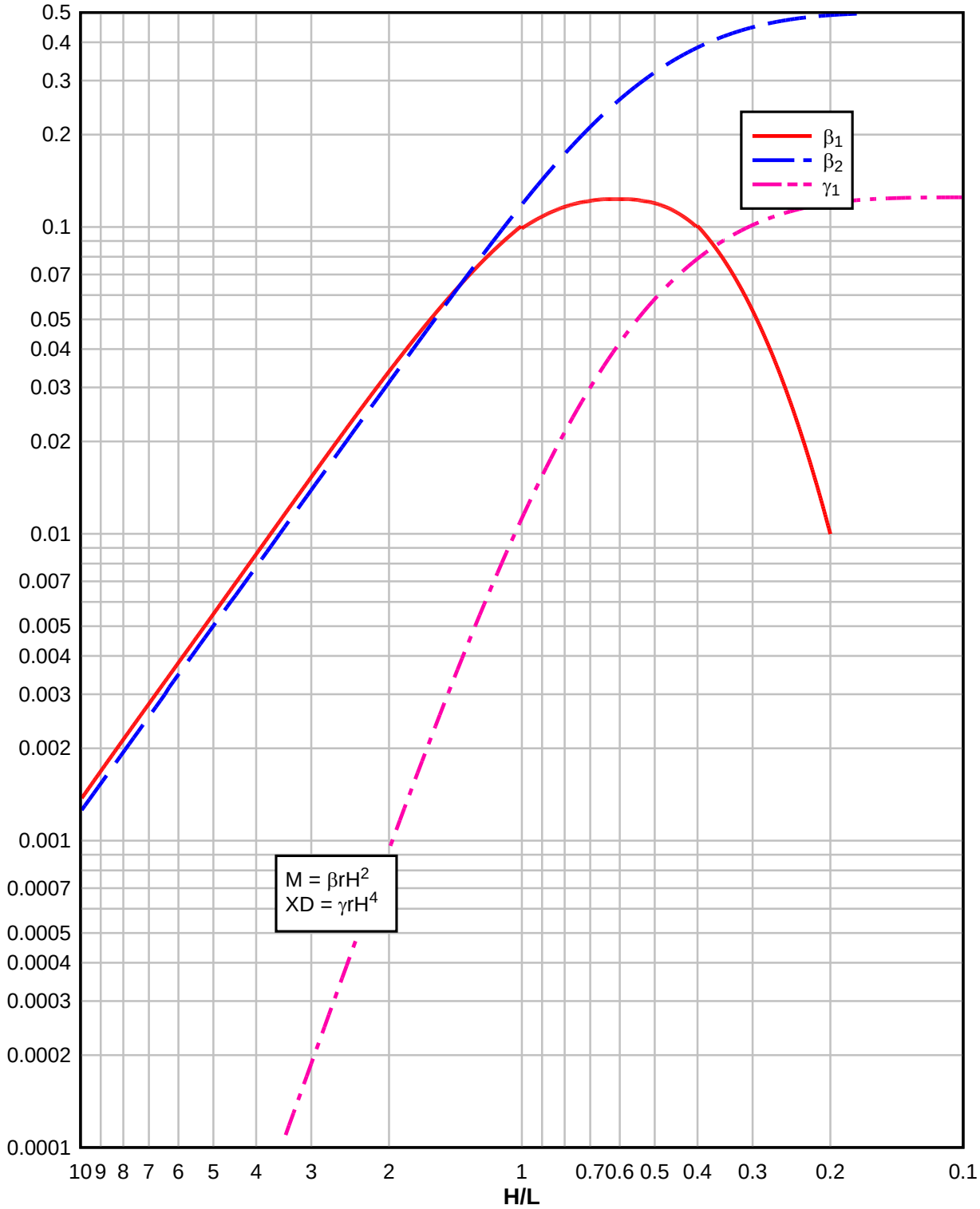


Figure 3-30 Moment and Deflection Coefficients for Uniformly-Loaded, Two-Way Element with Three Edges Simply-Supported and One Edge Free

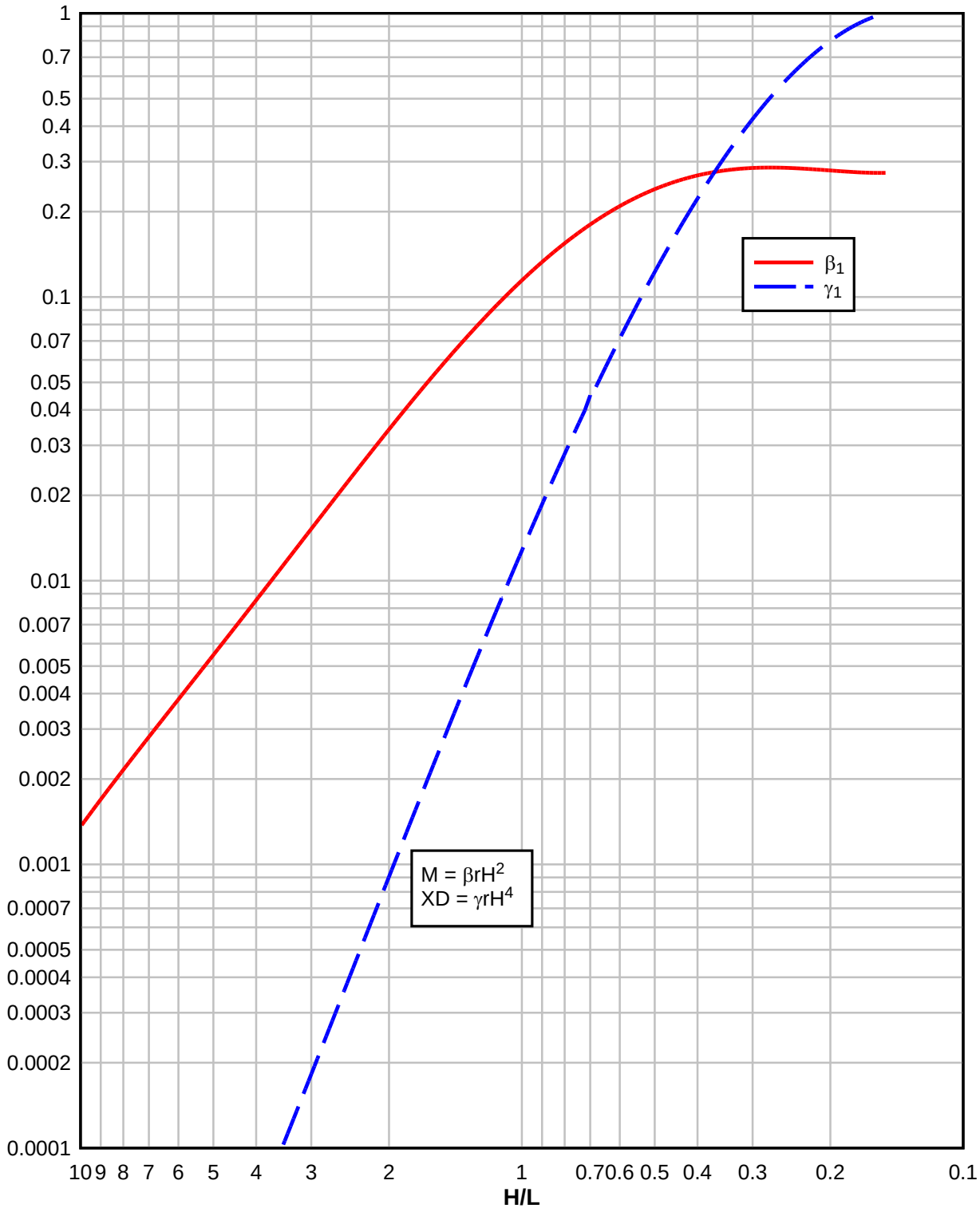


Figure 3-31 Moment and Deflection Coefficients for Uniformly-Loaded, Two-Way Element with Two Adjacent Edges Fixed, One Edge Simply-Supported, and One Edge Free

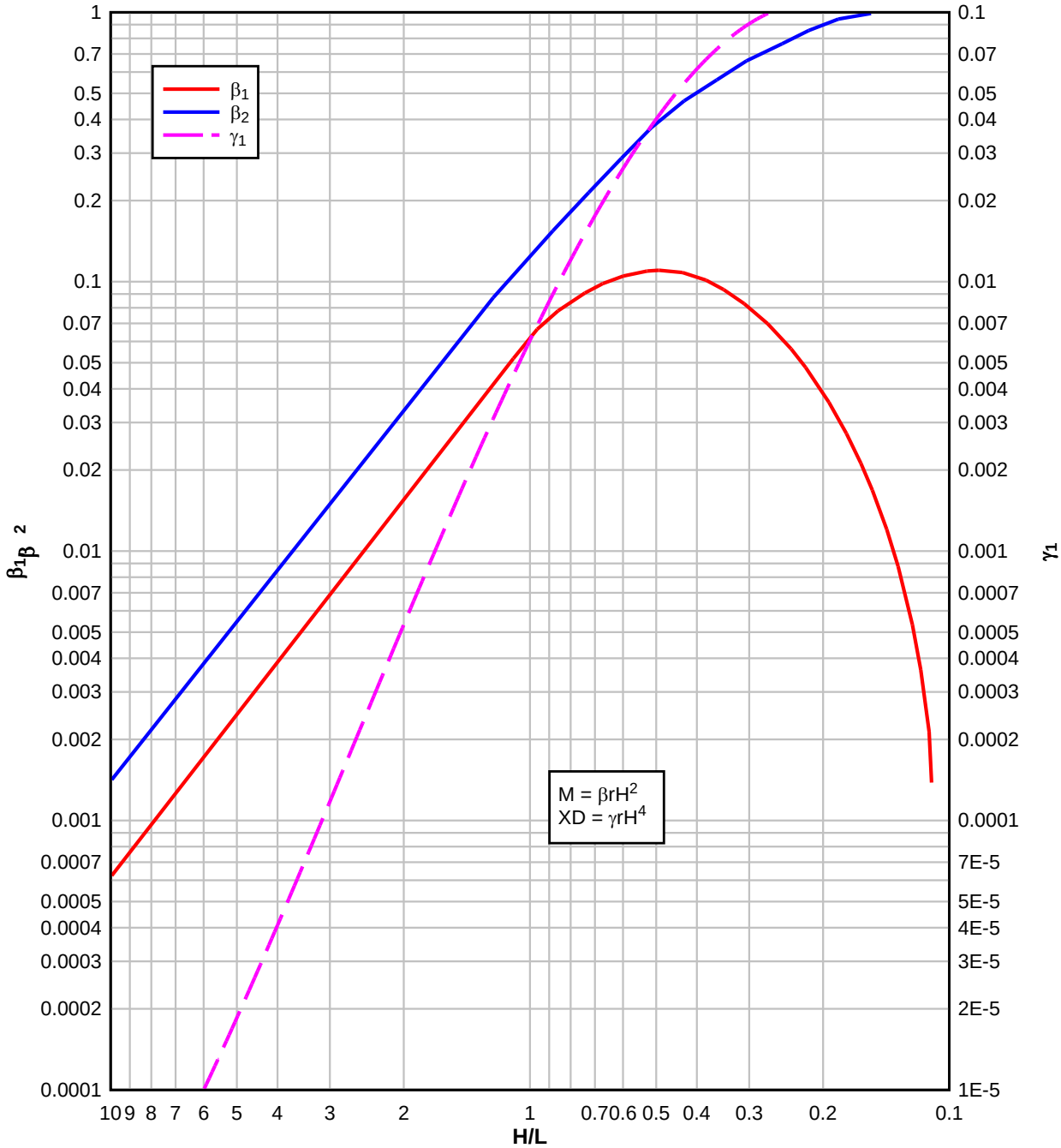


Figure 3-32 Moment and Deflection Coefficients for Uniformly-Loaded, Two-Way Element with Two Adjacent Edges Simply-Supported, One Edge Fixed, and One Edge Free

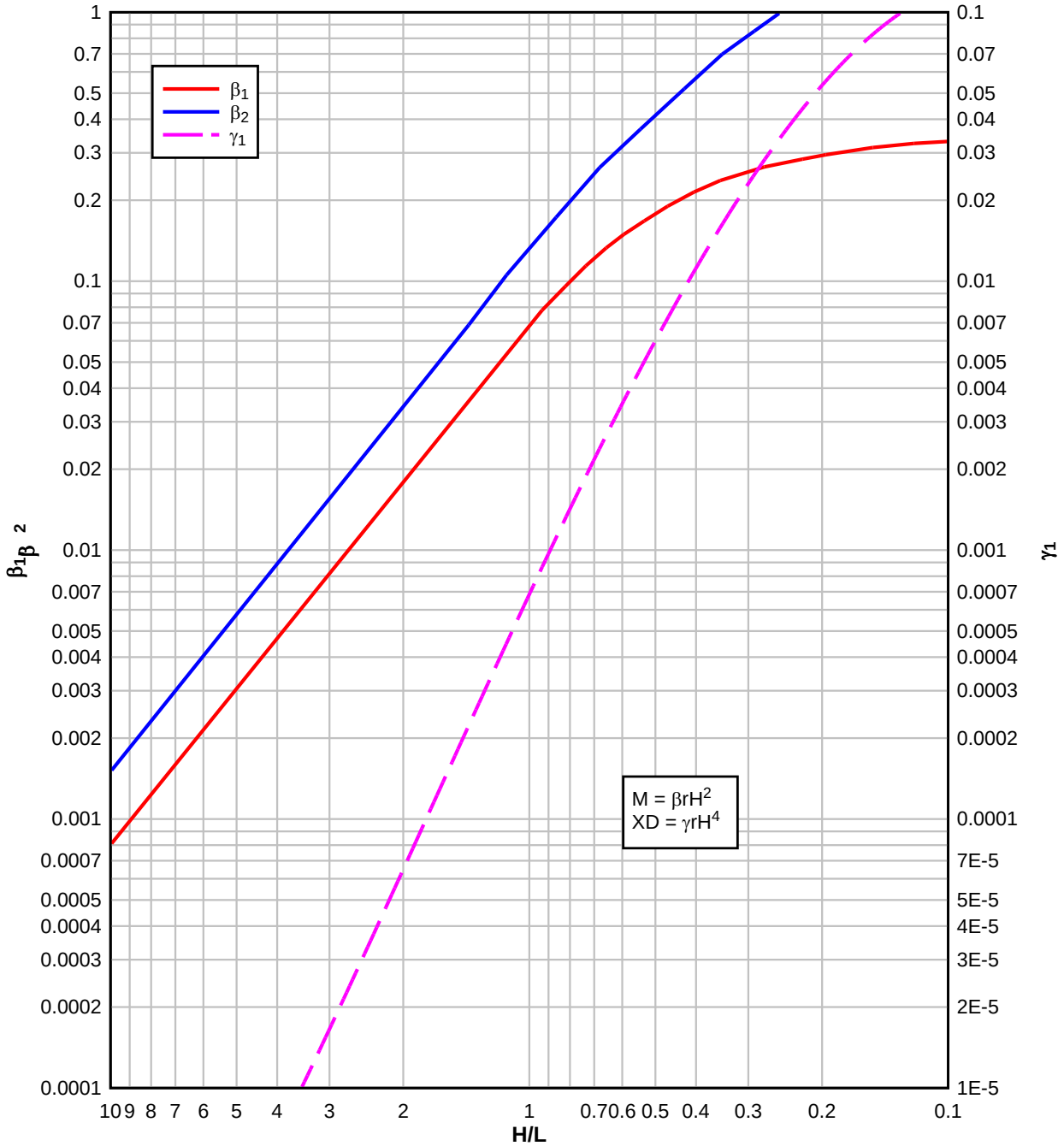


Figure 3-33 Moment and Deflection Coefficients for Uniformly-Loaded, Two-Way Element with All Edges Fixed

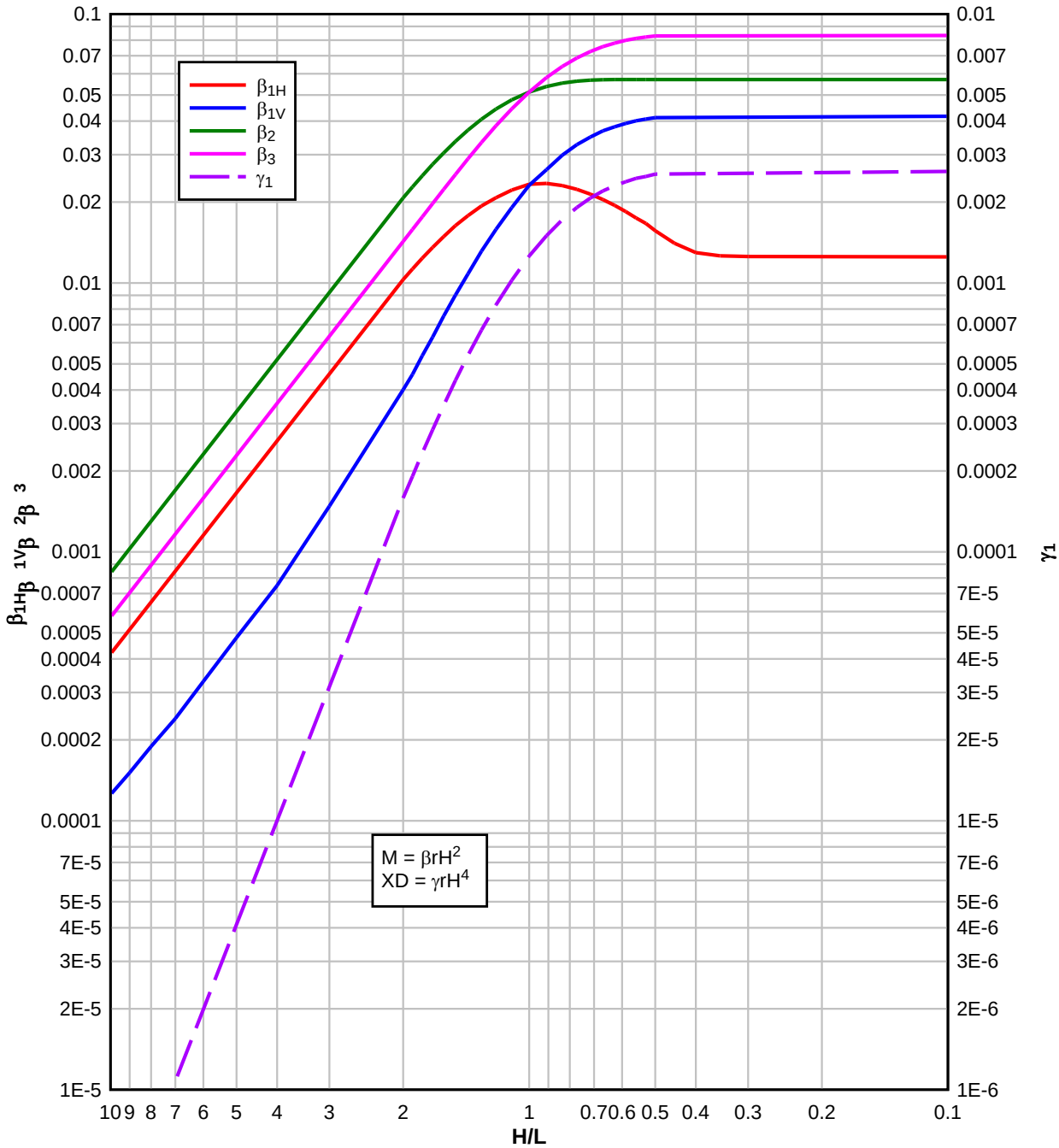


Figure 3-34 Moment and Deflection Coefficients for Uniformly-Loaded, Two-Way Element with Two Opposite Edges Fixed and Two Edges Simply-Supported

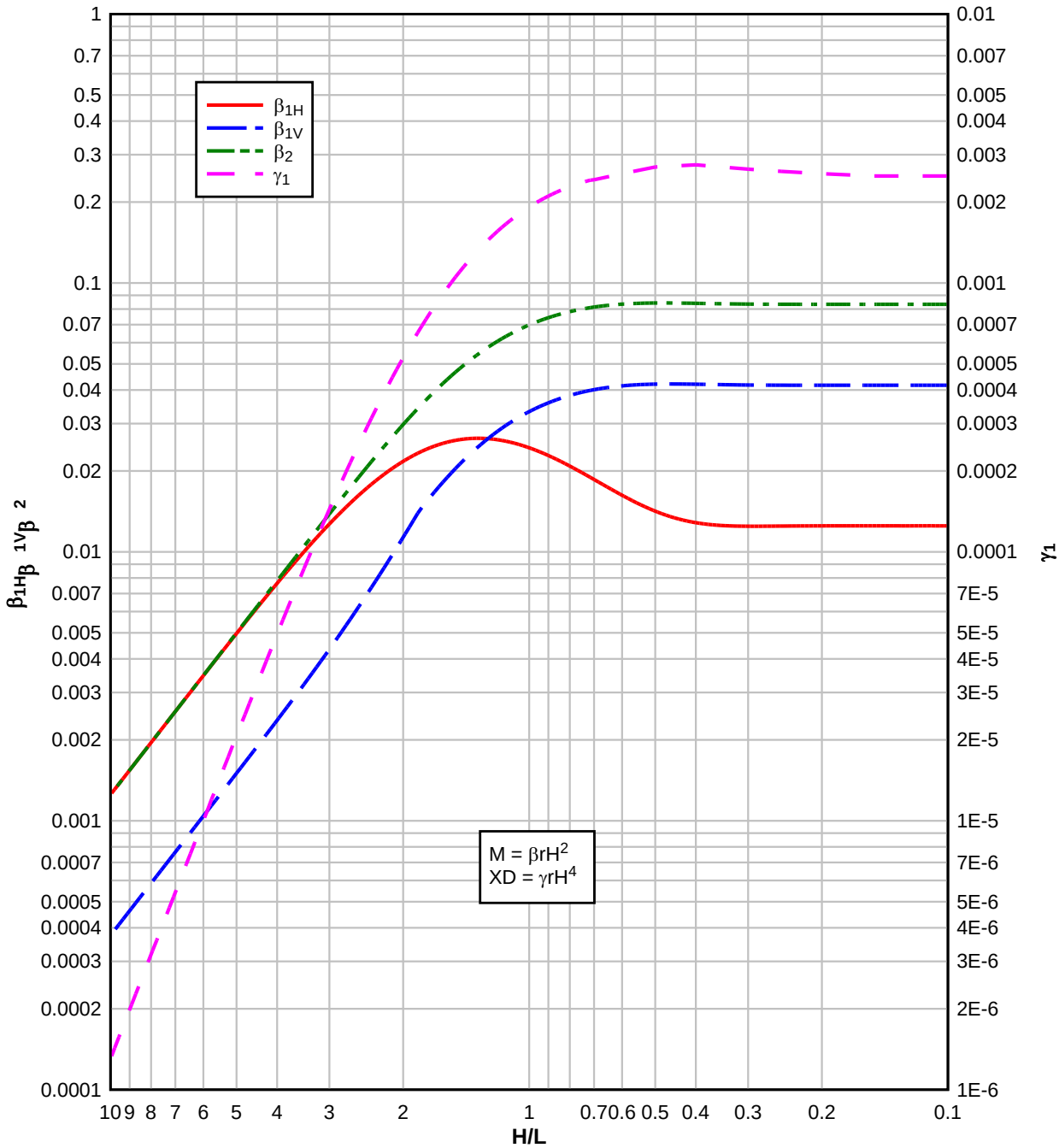


Figure 3-35 Moment and Deflection Coefficients for Uniformly-Loaded, Two-Way Element with Three Edges Fixed and One Edge Simply-Supported

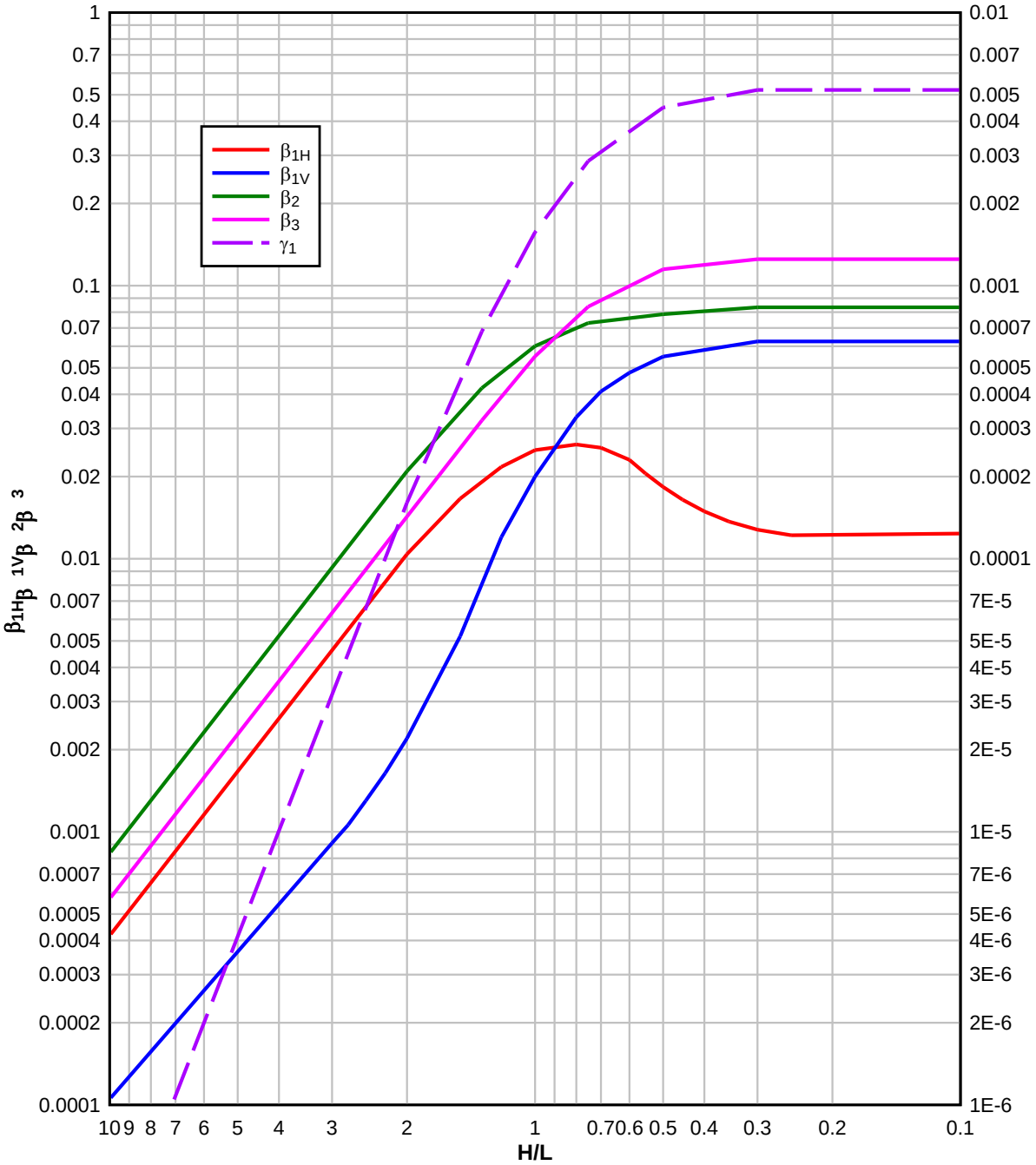


Figure 3-36 Moment and Deflection Coefficients for Uniformly-Loaded, Two-Way Element with All Edges Simply-Supported

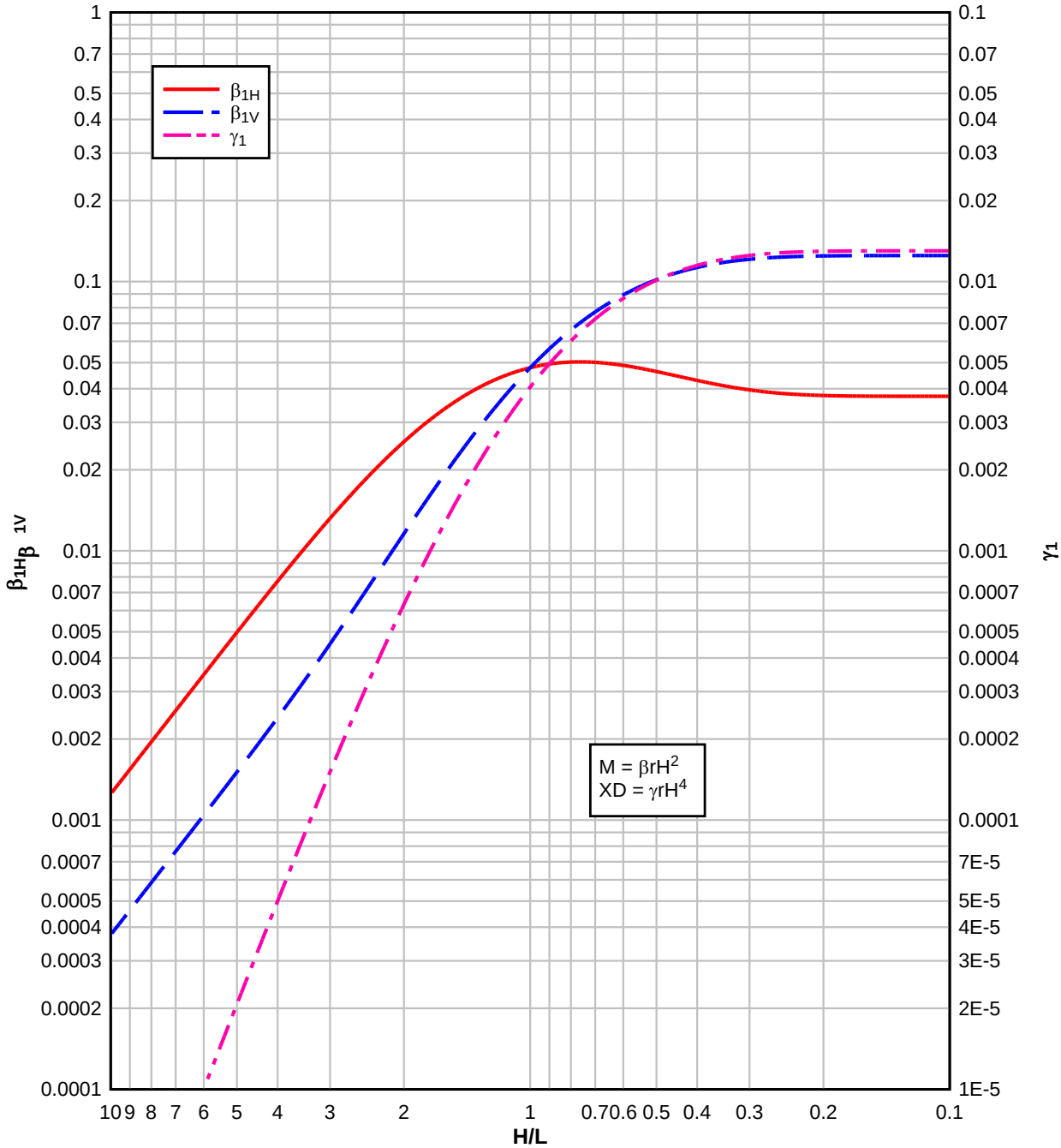


Figure 3-37 Moment and Deflection Coefficients for Uniformly-Loaded, Two-Way Element with Two Adjacent Edges Fixed, and Two Edges Simply-Supported

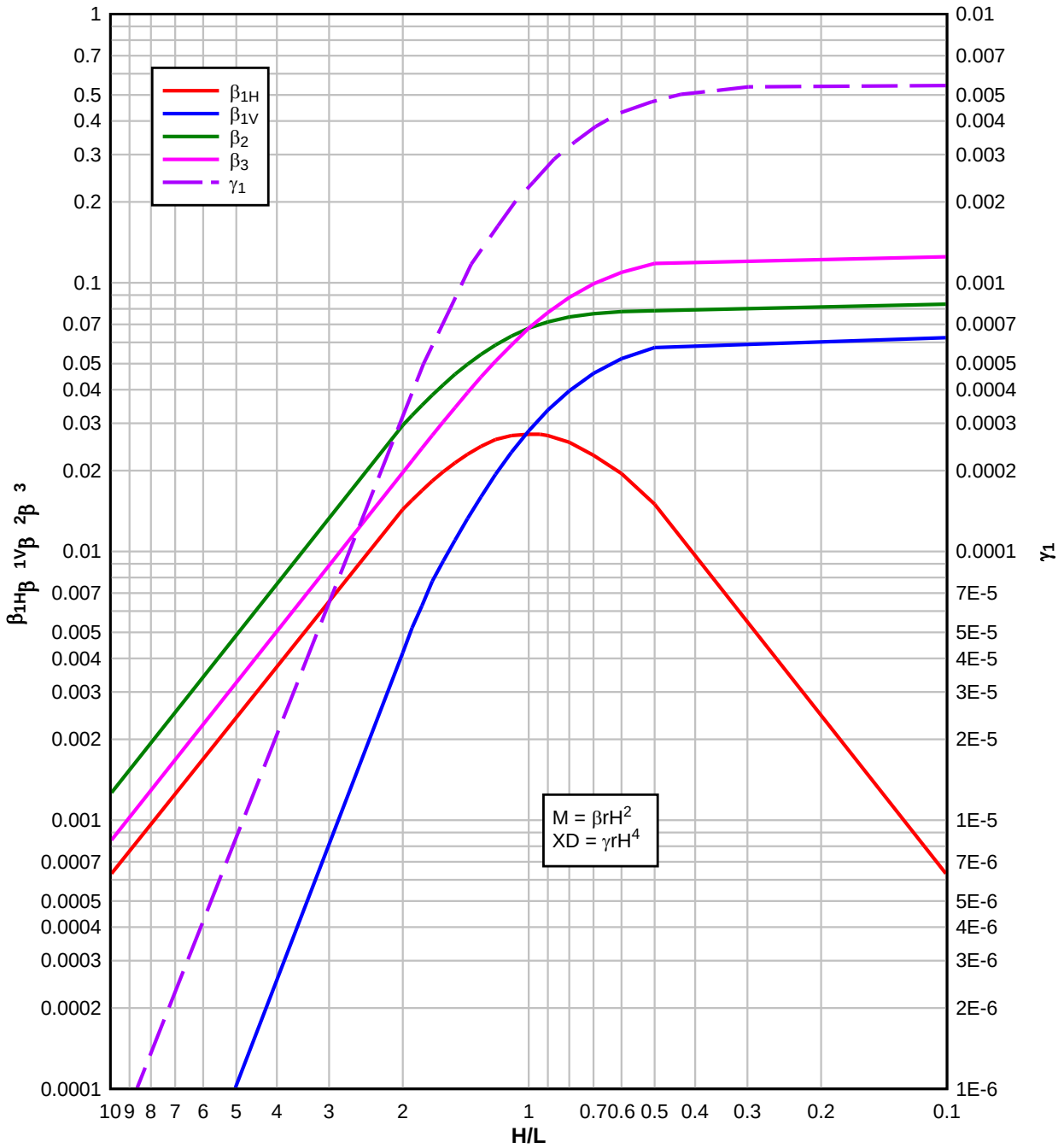


Figure 3-38 Moment and Deflection Coefficients for Uniformly-Loaded, Two-Way Element with Three Edges Simply-Supported and One Edge Fixed

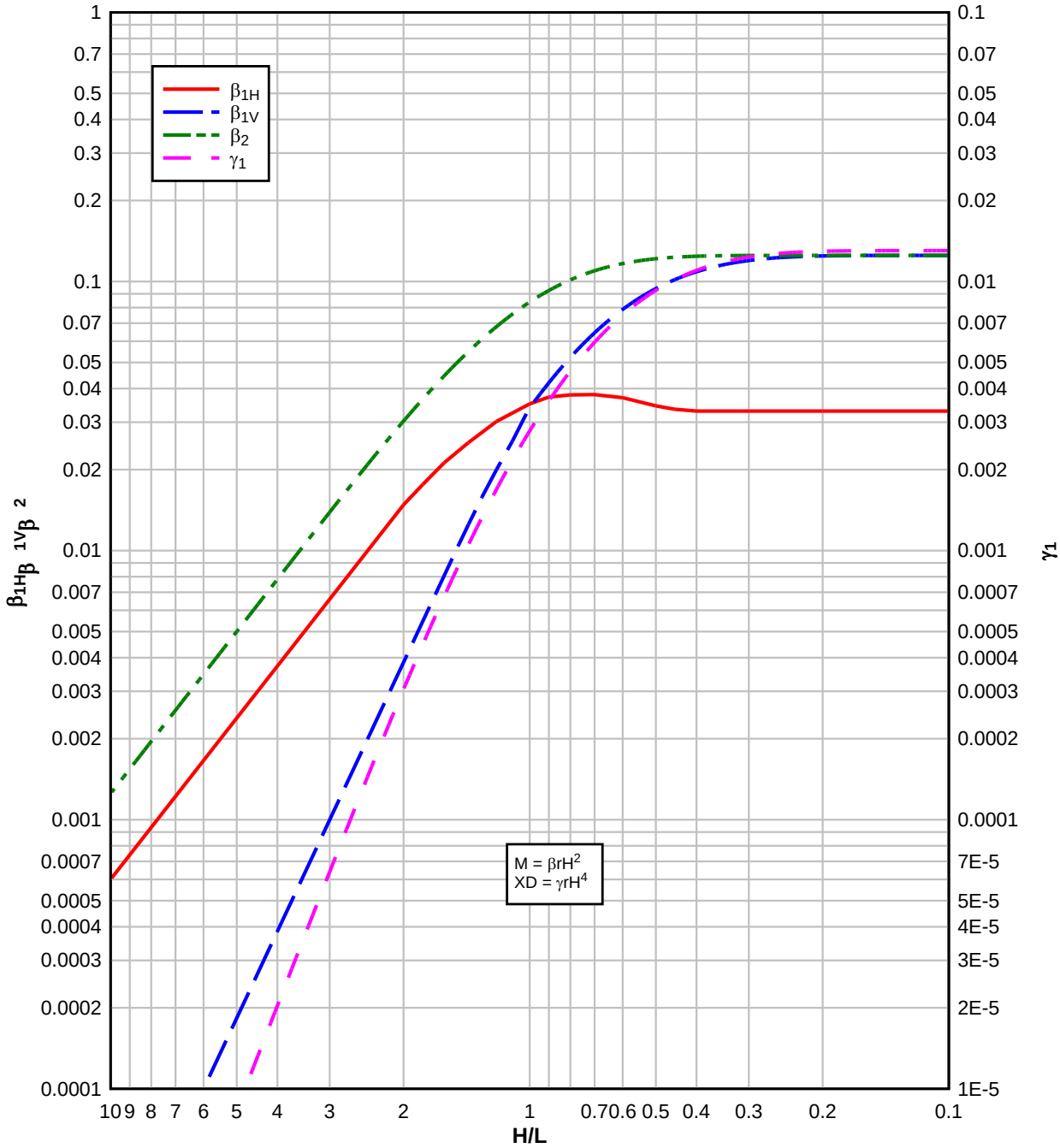


Figure 3-39 Resistance-Deflection Functions for Limited Deflections

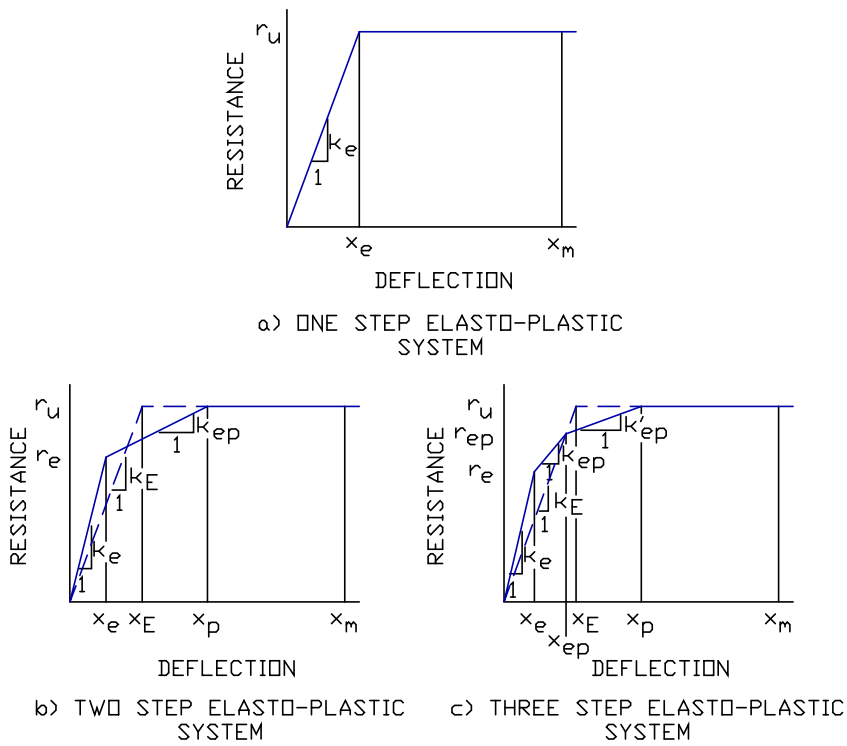


Figure 3-40 Resistance-Deflection Functions for Large Deflections

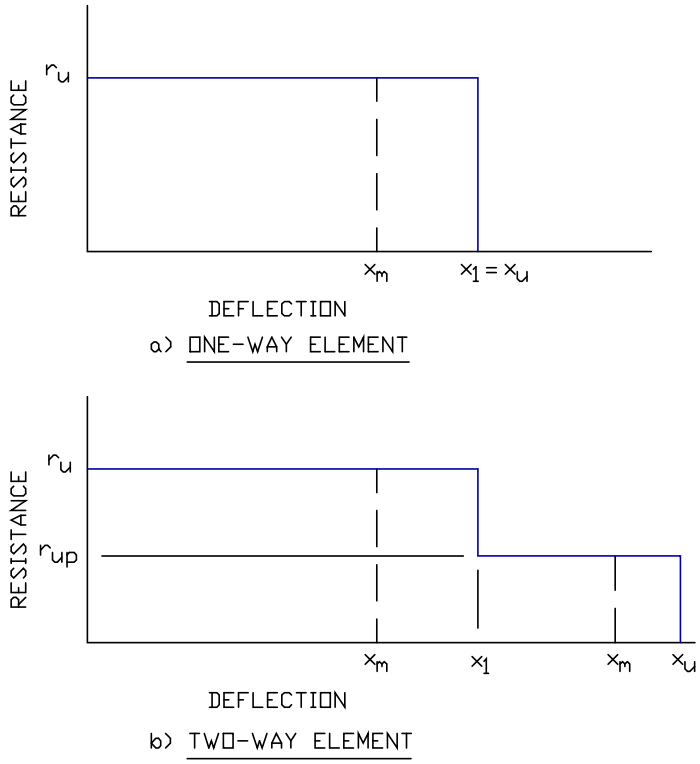


Figure 3-41 Determination of Ultimate Support Shear

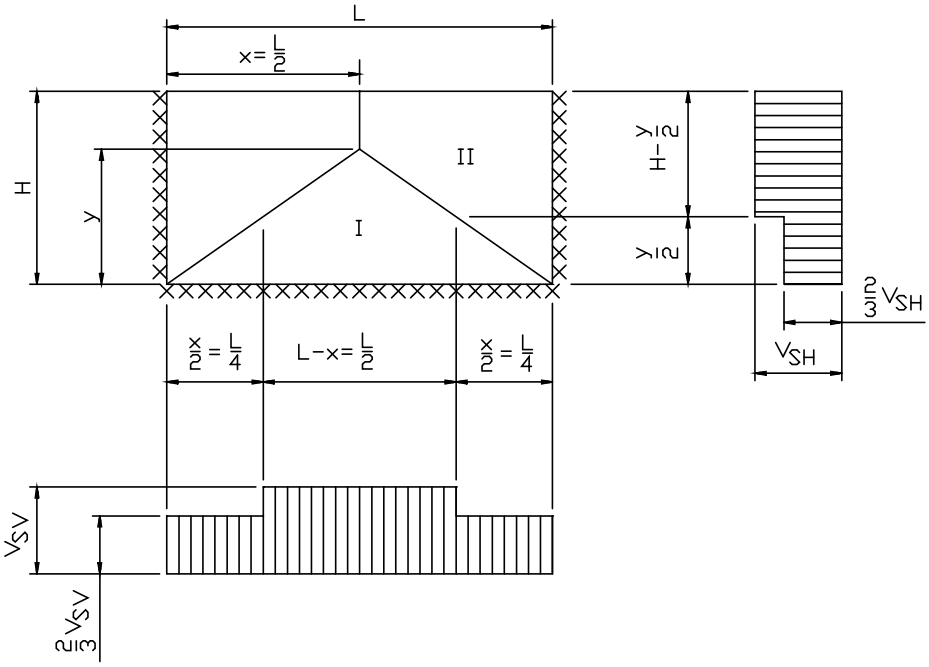


Table 3-1 Ultimate Unit Resistances for One-Way Elements

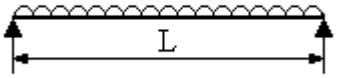
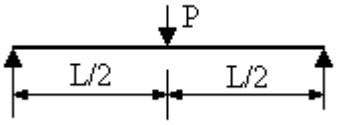
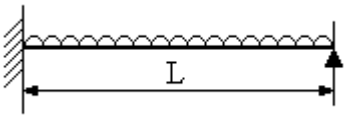
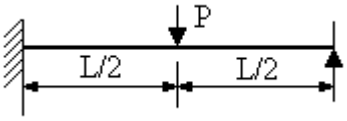
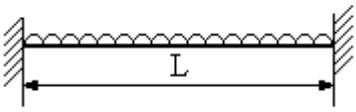
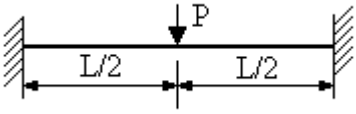
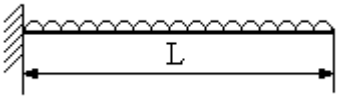
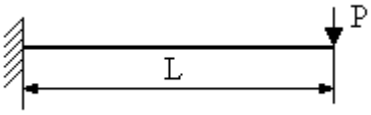
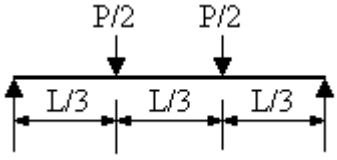
Edge Condition and Loading Diagrams	Ultimate Resistance
	$r_u = \frac{8M_p}{L^2}$
	$R_u = \frac{4M_p}{L}$
	$r_u = \frac{4(M_N + 2M_p)}{L^2}$
	$R_u = \frac{2(M_N + 2M_p)}{L}$
	$r_u = \frac{8(M_N + M_p)}{L^2}$
	$R_u = \frac{4(M_N + M_p)}{L}$
	$r_u = \frac{2M_N}{L^2}$
	$R_u = \frac{M_N}{L}$
	$R_u = \frac{6M_p}{L}$

Table 3-2 Ultimate Unit Resistances for Two-Way Elements (Symmetrical Yield Lines)

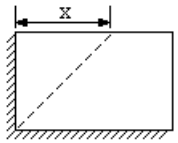
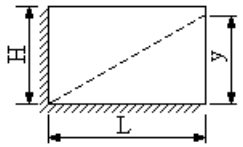
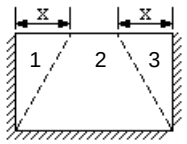
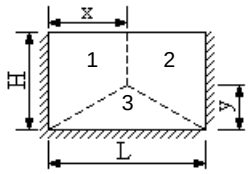
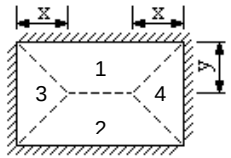
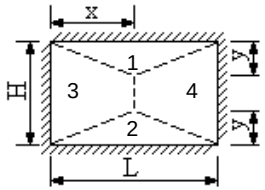
Edge Conditions	Yield Line Locations	Limits	Ultimate Unit Resistance
Two adjacent edges supported and two edges free		x ≤ L	$\frac{5(M_{HN}+M_{HP})}{x^2}$ OR $\frac{6LM_{VN}+(5M_{VP}-M_{VN})x}{H^2(3L-2x)}$
		y ≤ H	$\frac{5(M_{VN}+M_{VP})}{y^2}$ OR $\frac{6HM_{HN}+(5M_{HP}-M_{HN})y}{L^2(3H-2y)}$
Three edges supported and one edge free		x ≤ L/2	$\frac{5(M_{HN}+M_{HP})}{x^2}$ OR $\frac{2M_{VN}(3L-x)+10xM_{VP}}{H^2(3L-4x)}$
		y ≤ H	$\frac{5(M_{VN}+M_{VP})}{y^2}$ OR $\frac{4(M_{HN}+M_{HP})(6H-y)}{L^2(3H-2y)}$
Four edges supported		x ≤ L/2	$\frac{5(M_{HN}+M_{HP})}{x^2}$ OR $\frac{8(M_{VN}+M_{VP})(3L-x)}{H^2(3L-4x)}$
		y ≤ H/2	$\frac{5(M_{VN}+M_{VP})}{y^2}$ OR $\frac{8(M_{HN}+M_{HP})(3H-y)}{L^2(3H-4y)}$

Table 3-3 Ultimate Unit Resistances for Two-Way Elements (Unsymmetrical Yield Lines)

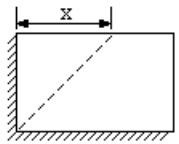
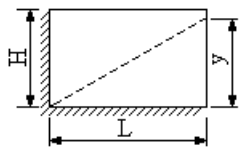
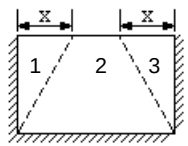
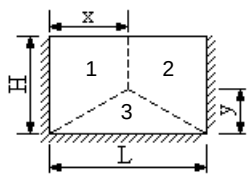
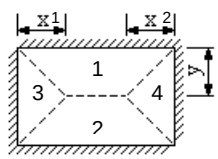
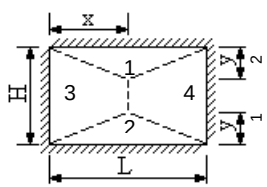
Edge Conditions	Yield Line Locations	Limits	Ultimate Unit Resistance
Two adjacent edges supported and two edges free	 	$x \le L$ $y \le H$	Same as in Table 3-2 (+)
Three edges supported and one edge free	 	$x \le L/2$ $y \le H$	$\frac{5(M_{HN1}+M_{HP1})}{x_1^{\,2}}$ OR $\frac{5(M_{HN3}+M_{HP})}{x_2^{\,2}}$ OR $\frac{(5M_{VP}-M_{VN2})(x_1+x_2)+6M_{VN2}L}{H^2(3L-2x_1-2x_2)}$ $\frac{(M_{HN1}+M_{HP})(6H-y)}{x^2(3H-2y)}$ OR $\frac{(M_{HN2}+M_{HP})(6H-y)}{(L-x)^2(3H-2y)}$ OR $\frac{5(M_{VN3}+M_{VP})}{y^2}$
Four edges supported	 	$x \le L/2$ $y \le H/2$	$\frac{(M_{VN1}+M_{VP})(6L-x_1-x_2)}{y^2(3L-2x_1-2x_2)}$ OR $\frac{(M_{VN2}+M_{VP})(6L-x_1-x_2)}{(H-y)^2(3L-2x_1-2x_2)}$ OR $\frac{5(M_{HN1}+M_{HP})}{x_1^{\,2}}$ OR $\frac{5(M_{HN2}+M_{HP})}{x_2^{\,2}}$ $\frac{5(M_{VN1}+M_{VP})}{y_1^{\,2}}$ OR $\frac{5(M_{VN2}+M_{VP})}{y_2^{\,2}}$ OR $\frac{(M_{HN1}+M_{HP})(6H-y_1-y_2)}{x^2(3H-2y_1-2y_2)}$ OR $\frac{(M_{HN2}+M_{HP})(6H-y_1-y_2)}{(L-x)^2(3H-2y_1-2y_2)}$

Table 3-4 Post-Ultimate Unit Resistances for Two-Way Elements

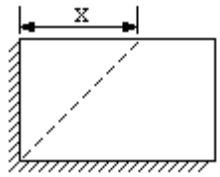
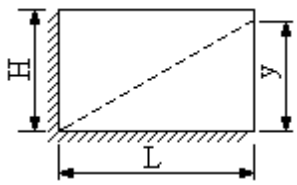
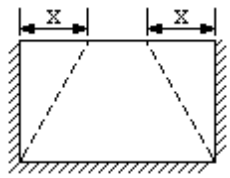
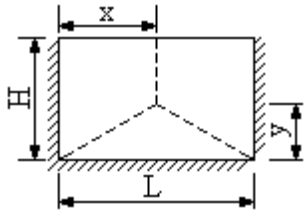
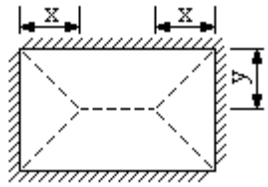
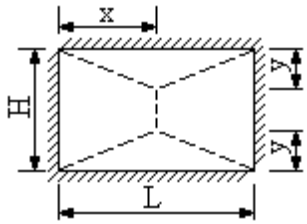
Edge Conditions	Yield Line Locations	Limits	Post-Ultimate Unit Resistance
Two adjacent edges supported and two edges free		$x < H$ $x > H$	$2M_{VN}/H^2$ $2M_{HN}/L^2$
		$y < L$ $y > L$	$2M_{HN}/L^2$ $2M_{VN}/H^2$
Three edges supported and one edge free		$x < H$ $x > H$	$2M_{VN}/H^2$ $8(M_{HN}+M_{HP})/L^2$
		$y < L/2$ $y > L/2$	$8(M_{HN}+M_{HP})/L^2$ $2M_{VN}/H^2$
Four edges supported		$x < H/2$ $x > H/2$	$8(M_{VN}+M_{VP})/H^2$ $8(M_{HN}+M_{HP})/L^2$
		$y < L/2$ $y > L/2$	$8(M_{VN}+M_{VP})/L^2$ $8(M_{HN}+M_{HP})/H^2$

Table 3-5 General and Ultimate Deflections for One-Way Elements

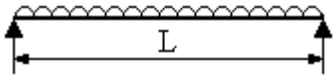
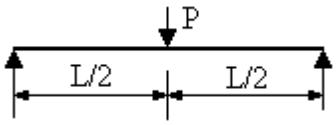
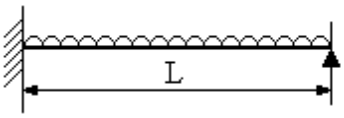
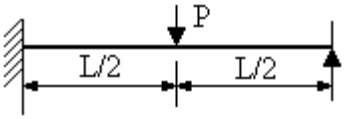
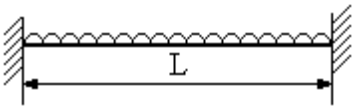
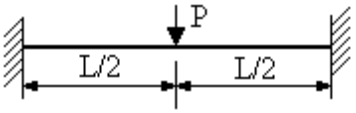
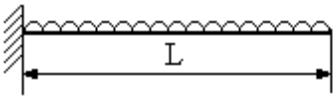
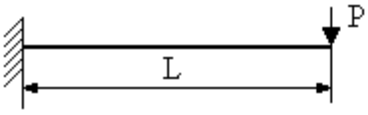
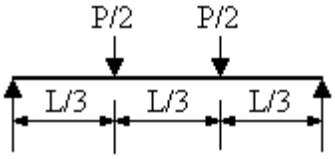
Edge Conditions and Loading Diagrams	Maximum Deflection, X_m	Ultimate Deflection, X_u
	$\frac{L}{2}\tan\theta$	$\frac{L}{2}\tan\theta_{max}$
	$\frac{L}{2}\tan\theta$	$\frac{L}{2}\tan\theta_{max}$
	$\frac{L}{2}\tan\theta$	$\frac{L}{2}\tan\theta_{max}$
	$\frac{L}{2}\tan\theta$	$\frac{L}{2}\tan\theta_{max}$
	$\frac{L}{2}\tan\theta$	$\frac{L}{2}\tan\theta_{max}$
	$\frac{L}{2}\tan\theta$	$\frac{L}{2}\tan\theta_{max}$
	$L\tan\theta$	$L\tan\theta_{max}$
	$L\tan\theta$	$L\tan\theta_{max}$
	$\frac{L}{3}\tan\theta$	$\frac{L}{3}\tan\theta_{max}$

Table 3-6 General, Partial Failure, and Ultimate Deflections for Two-Way Elements

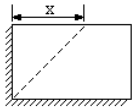
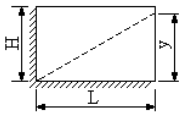
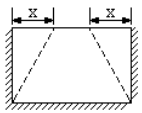
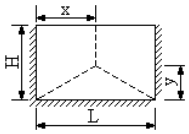
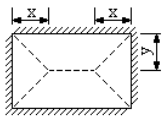
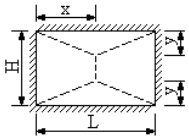
Edge Conditions	Yield Line Location	Limits	Maximum Deflection, x_m		Partial Failure Deflection, x_1	Ultimate Deflection, x_u	Support Failing Deflection x_1
			$(0<x_m<x_1)$	$(x_1<x_m<x_u)$			
Two adjacent edges supported and two edges free		$x \le H$	$x\tan\theta_H$	$H\tan\theta_V$	$x\tan\theta_{max}$	$H\tan\theta_{max}$	H
		$x \ge H$	$H\tan\theta_V$	$x\tan\theta_H+(L-x)\tan\left[\theta_H-\tan^{-1}\left(\frac{\tan\theta_V}{x/H}\right)\right]$	$H\tan\theta_{max}$	$x\tan\theta_{max}+(L-x)\tan\left[\theta_{max}-\tan^{-1}\left(\frac{\tan\theta_{max}}{x/H}\right)\right]$	L
		$y \le L$	$y\tan\theta_V$	$L\tan\theta_H$	$y\tan\theta_{max}$	$L\tan\theta_{max}$	L
		$y \ge L$	$L\tan\theta_H$	$y\tan\theta_V+(H-y)\tan\left[\theta_V-\tan^{-1}\left(\frac{\tan\theta_H}{y/L}\right)\right]$	$L\tan\theta_{max}$	$y\tan\theta_{max}+(H-y)\tan\left[\theta_{max}-\tan^{-1}\left(\frac{\tan\theta_{max}}{y/L}\right)\right]$	H
Three edges supported and one edge free		$x \le H$	$x\tan\theta_V$	$H\tan\theta_V$	$x\tan\theta_{max}$	$H\tan\theta_{max}$	H
		$x \ge H$	$H\tan\theta_V$	$x\tan\theta_H+\left(\frac{L}{2}-x\right)\tan\left[\theta_H-\tan^{-1}\left(\frac{\tan\theta_V}{x/H}\right)\right]$	$H\tan\theta_{max}$	$x\tan\theta_{max}+\left(\frac{L}{2}-x\right)\tan\left[\theta_{max}-\tan^{-1}\left(\frac{\tan\theta_{max}}{x/H}\right)\right]$	L
		$y \le L/2$	$y\tan\theta_V$	$\frac{L\tan\theta_H}{2}$	$y\tan\theta_{max}$	$\frac{L\tan\theta_{max}}{2}$	L
		$y \ge L/2$	$\frac{L\tan\theta_H}{2}$	$y\tan\theta_V+(H-y)\tan\left[\theta_V-\tan^{-1}\left(\frac{\tan\theta_H}{2y/L}\right)\right]$	$\frac{L\tan\theta_{max}}{2}$	$y\tan\theta_{max}+(H-y)\tan\left[\theta_{max}-\tan^{-1}\left(\frac{\tan\theta_{max}}{2y/L}\right)\right]$	H
Four edges supported		$x \le H/2$	$x\tan\theta_H$	$\frac{H\tan\theta_V}{2}$	$x\tan\theta_{max}$	$\frac{H\tan\theta_{max}}{2}$	H
		$x \ge H/2$	$\frac{H\tan\theta_V}{2}$	$x\tan\theta_H+\left(\frac{L}{2}-x\right)\tan\left[\theta_H-\tan^{-1}\left(\frac{\tan\theta_V}{2x/H}\right)\right]$	$\frac{H\tan\theta_{max}}{2}$	$x\tan\theta_{max}+\left(\frac{L}{2}-x\right)\tan\left[\theta_{max}-\tan^{-1}\left(\frac{\tan\theta_{max}}{2x/H}\right)\right]$	L
		$y \le L/2$	$y\tan\theta_V$	$\frac{L\tan\theta_H}{2}$	$y\tan\theta_{max}$	$\frac{L\tan\theta_{max}}{2}$	L
		$y \ge L/2$	$\frac{L\tan\theta_H}{2}$	$y\tan\theta_V+\left(\frac{H}{2}-y\right)\tan\left[\theta_V-\tan^{-1}\left(\frac{\tan\theta_H}{2y/L}\right)\right]$	$\frac{L\tan\theta_{max}}{2}$	$y\tan\theta_{max}+\left(\frac{H}{2}-y\right)\tan\left[\theta_{max}-\tan^{-1}\left(\frac{\tan\theta_{max}}{2y/L}\right)\right]$	H

Table 3-7 Elastic and Elasto-Plastic Unit Resistances for One-Way Elements

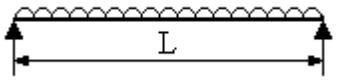
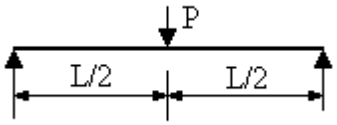
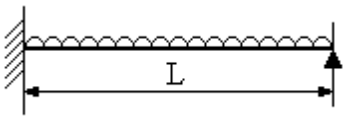
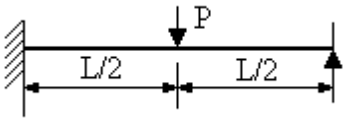
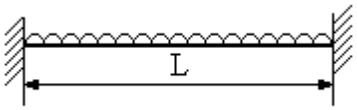
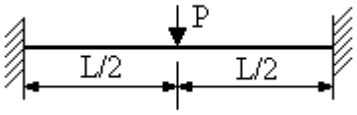
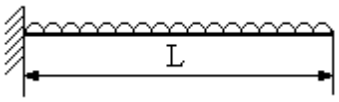
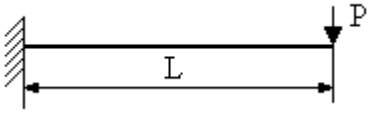
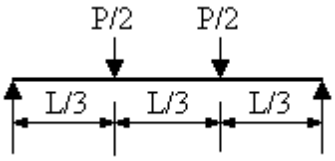
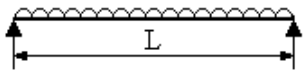
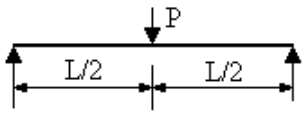
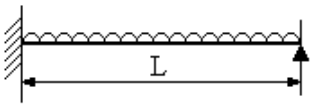
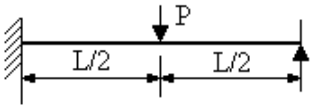
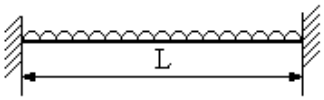
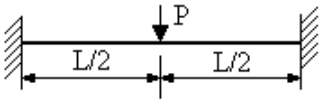
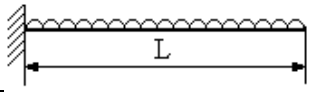
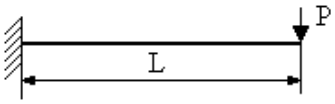
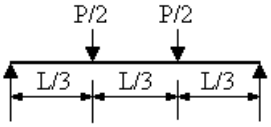
Edge Conditions and Loading Diagrams	Elastic Resistance, r_e	Elasto-Plastic Resistance, r_{ep}
	r_u	-----
	R_u	-----
	$\frac{8M_N}{L^2}$	r_u
	$\frac{16M_N}{3L}$	R_u
	$\frac{12M_N}{L^2}$	r_u
	$\frac{8M_N}{L}$	R_u
	r_u	-----
	R_u	-----
	R_u	-----

Table 3-8 Elastic, Elasto-Plastic and Equivalent Elastic Stiffnesses for One-Way Elements

Edge Conditions and Loading Diagrams	Elastic Stiffness, K_e	Elasto-Plastic Stiffness, K_{ep}	Equivalent Elastic Stiffness, K_E
	$\frac{384EI}{5L^4}$	———	$\frac{384EI}{5L^4}$
	$\frac{48EI}{L^3}$	———	$\frac{48EI}{L^3}$
	$\frac{185EI}{L^4}$	$\frac{384EI}{5L^4}$	$\frac{160EI}{L^4}$ *
	$\frac{107EI}{L^3}$	$\frac{48EI}{L^3}$	$\frac{106EI}{L^3}$ *
	$\frac{384EI}{L^4}$	$\frac{384EI}{5L^4}$	$\frac{307EI}{L^4}$ *
	$\frac{192EI}{L^3}$	$\frac{48EI}{L^3}$ **	$\frac{192EI}{L^3}$ *
	$\frac{8EI}{L^4}$	———	$\frac{8EI}{L^4}$
	$\frac{3EI}{L^3}$	———	$\frac{3EI}{L^3}$
	$\frac{56.4EI}{L^3}$	———	$\frac{56.4EI}{L^3}$

* Valid only if $M_N = M_P$

** Valid only if $M_N < M_P$

Table 3-9 Support Shears for One-Way Elements

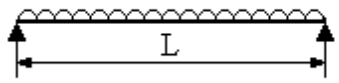
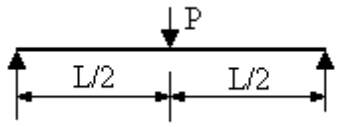
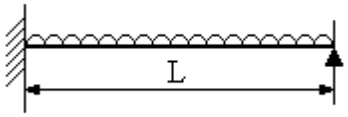
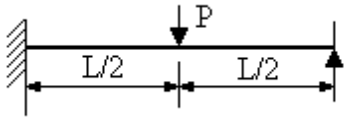
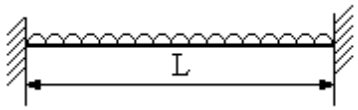
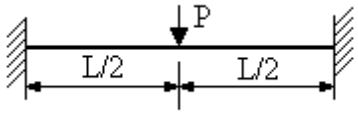
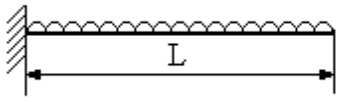
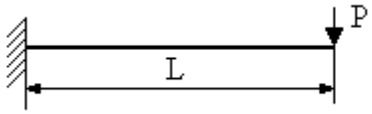
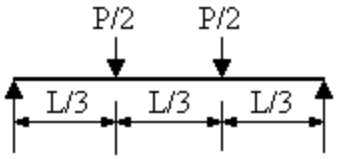
Edge Conditions and Loading Diagrams	Support Reactions, V_s
	$\frac{r_u L}{2}$
	$\frac{R_u}{2}$
	L.Reaction $\frac{5r_u L}{8}$ R.Reaction $\frac{3r_u L}{8}$
	L.Reaction $\frac{11R_u}{16}$ R.Reaction $\frac{5R_u}{16}$
	$\frac{r_u L}{2}$
	$\frac{R_u}{2}$
	$r_u L$
	R_u
	$\frac{R_u}{2}$

Table 3-10 Ultimate Support Shears for Two-Way Elements (Symmetrical Yield Lines)

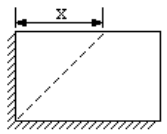
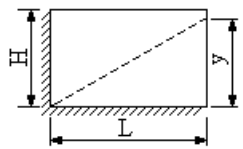
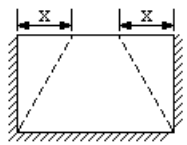
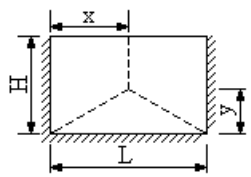
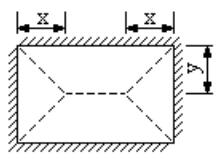
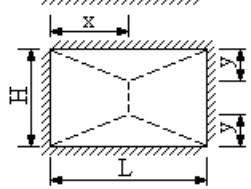
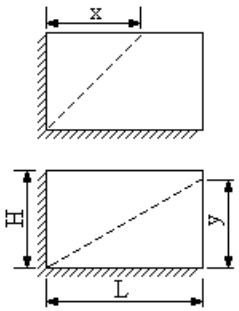
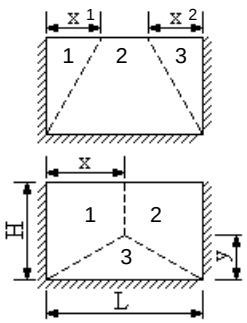
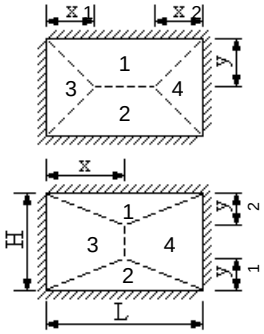
Edge Conditions	Yield Line Locations	Limits	Horizontal shear, V_{sH}	Vertical shear, V_{sV}
Two adjacent edges supported and two edges free	 	$x \le L$ $y \le H$	$\frac{3r_u x}{5}$ $\frac{3r_u L\left(2-\frac{y}{H}\right)}{\left(6-\frac{y}{H}\right)}$	$\frac{3r_u H\left(2-\frac{x}{L}\right)}{\left(6-\frac{x}{L}\right)}$ $\frac{3r_u y}{5}$
Three edges supported and one edge free	 	$x \le \frac{L}{2}$ $y \le H$	$\frac{3r_u x}{5}$ $\frac{3r_u L\left(2-\frac{y}{H}\right)}{2\left(6-\frac{y}{H}\right)}$	$\frac{3r_u H\left(1-\frac{x}{L}\right)}{\left(3-\frac{x}{L}\right)}$ $\frac{3r_u y}{5}$
Four edges supported	 	$x \le \frac{L}{2}$ $y \le \frac{H}{2}$	$\frac{3r_u x}{5}$ $\frac{3r_u L\left(1-\frac{y}{H}\right)}{2\left(3-\frac{y}{H}\right)}$	$\frac{3r_u H\left(1-\frac{x}{L}\right)}{2\left(3-\frac{x}{L}\right)}$ $\frac{3r_u y}{5}$

Table 3-11 Ultimate Support Shears for Two Way Elements (Unsymmetrical Yield Lines)

Edge Conditions	Yield Line Locations	Limits	Horizontal shear, V_{sH}	Vertical shear, V_{sV}
Two adjacent edges supported and two edges free		$x \le L$ $y \le H$	Same as in Table 3-10 (+)	Same as in Table 3-10 (+)
Three edges supported and one edge free		$x_1 \le \frac{L}{2}$ $x_2 \le \frac{L}{2}$ $y \le H$	$\frac{3x_1 r_u}{5}$ $\frac{3x_2 r_u}{5}$ $\frac{3r_u x(2H-y)}{6H-y}$ $\frac{3r_u (L-x)(2H-y)}{6H-y}$	$\frac{3r_u H(2L-x_1-x_2)}{6L-x_1-x_2}$ $\frac{3r_u y}{5}$
Four edges supported		$x_1 \le \frac{L}{2}$ $x_2 \le \frac{L}{2}$ $y_1 \le \frac{H}{2}$ $y_2 \le \frac{H}{2}$	$\frac{3r_u x_1}{5}$ $\frac{3r_u x_2}{5}$ $\frac{3r_u x(2H-y_1-y_2)}{6H-y_1-y_2}$ $\frac{3r_u x(L-x)(2H-y_1-y_2)}{6H-y_1-y_2}$	$\frac{3r_u y(2L-x_1-x_2)}{6L-x_1-x_2}$ $\frac{3r_u (H-y)(2L-x_1-x_2)}{6L-x_1-x_2}$ $\frac{3r_u y_1}{5}$ $\frac{3r_u y_2}{5}$

DYNAMICALLY EQUIVALENT SYSTEMS

3-16 INTRODUCTION.

In dynamic analysis, there are only three quantities to be considered: (1) the work done, (2) the strain energy, and (3) the kinetic energy. To evaluate the work done, the displacement at any point on the structure under externally distributed or concentrated loads must be known. The strain energy is equal to the summation of the strain energies in all the structural elements which may be in bending, tension, compression, shear or torsion. The kinetic energy involves the energy of translation and rotation of all the masses of the structure. The actual evaluation of these quantities for a given structure under dynamic load would be complicated. However, for practical problems, this can be avoided by using appropriate assumptions.

In most cases, a structure can be replaced by an idealized (or dynamically equivalent) system which behaves in nearly the same manner as the actual structure. The distributed masses of the given structure are lumped together into a number of concentrated masses. The strain energy is assumed to be stored in several weightless springs which do not have to behave elastically; similarly, the distributed load is replaced by a number of concentrated loads acting on the concentrated masses. Therefore, the equivalent system consists merely of a number of concentrated masses joined together by weightless springs and subjected to concentrated loads which vary with time. This concentrated mass-spring-load system is defined as an equivalent dynamic system.

Although all structural components possess many degrees of freedom, one mode usually predominates in the response to short duration loads; thus, for all practical purposes, this one mode may be considered to define the behavior of the structure and the problem can be simplified by considering a single-degree-of-freedom system whose properties are based on the fundamental response mode of the structural component. A single-degree-of-freedom (SDOF) system is defined as one in which only one type of motion is possible or, in other words, only one coordinate is required to define its motion. Such a system is shown in Figure 3-42 (+) which consists of a concentrated mass on a frictionless surface attached to a weightless spring and subjected to a concentrated load. A single displacement variable x is sufficient to describe its motion. The material presented herein will be limited to single-degree-of-freedom systems only.

Components in some structures, however, cannot be adequately modeled by only considering dynamic response in their first mode with a SDOF approach, particularly when consideration of dynamic strain is necessary. For these situations, a two-(or more)-degree-of-freedom analysis may be required. Procedures are presented in section 3-19.2 for performing these analyses.

Two fundamental methods are available for treating simple systems subjected to dynamic forces. The first of these methods solves the differential equations of motion of the system by either classical, numerical, or graphical means. The second method uses analysis and chart solutions determined by the use of the first method and are

approximate solutions. There is a third method which may also be very useful in vibrational problems that involves the energy equation.

In the following paragraphs the design factors used to define the parameters of an equivalent spring-mass system that represents a structural element are defined and the methods used to obtain these factors are discussed.

3-17 DYNAMIC DESIGN FACTORS.

3-17.1 Introduction.

The values of the mass and external force used in the equation of motion (Equation 3-1) are the actual values only if all the elements of the mass of the structure experience the same force and, consequently, move as a unit, in which case, the entire mass may be assumed to be concentrated at its center of gravity. In other cases, the assumption of uniform motion of the entire mass cannot be made without introducing serious error. This is true for members with uniformly distributed mass which bend or rotate under load. In such cases, the motion of the particles of mass varies along the length of the member. Beams, slabs, etc., with such distributed mass actually have an infinite number of degrees of freedom; however, such structural elements can be represented by an equivalent single-degree-of-freedom system.

In order to define an equivalent one-degree system, it is necessary to evaluate the parameters of that system; namely, the equivalent mass M_E, the equivalent spring constant K_E and the equivalent load F_E. The equivalent system is selected usually so that the deflection of the concentrated mass is the same as that for a significant point of the structure. The single-degree-of-freedom approximation of the dynamic behavior of the structural element may be achieved by assuming a deflected shape for the element which is usually taken as the shape resulting from the static application of the dynamic loads. The assumption of a deflected shape establishes an equation relating the relative deflection of all points of the element.

The accuracy of the computed response of the single-degree-of-freedom system is dependent on the assumed deflected shape and the loading region. For example, in the impulsive loading realm, if the assumed deformed shape for a simply supported beam is taken to be a parabola, then the exact solution will be obtained for the deflection of the beam. In the quasi-static loading realm, however, the static deformed shape gives the exact answer. For blast resistance design, however, the differences in either a static deformed shape or a first mode approximation is negligible and thus either way is permissible. Usually, though, the static deformed shape is easier to use as it covers both symmetric and asymmetric deformation.

To permit rapid design of structural elements subjected to dynamic loads, it is convenient to introduce design or transformation factors. These factors are used to convert parameters of the actual blast-loaded component to corresponding parameters defining the equivalent system. To obtain them, it is necessary to equate the relations expressing the kinetic energy, strain and work done on the actual structural element

deflecting according to the assumed deflected shape, with the corresponding relations for the equivalent SDOF mass and spring system.

3-17.2 Load, Mass, and Resistance Factors.

3-17.2.1 Load Factor.

The load factor is the design or transformation factor by which the total load applied on the structural element is multiplied to obtain the equivalent concentrated load for the equivalent single-degree-of-freedom system. If the actual total load on the structure is F and the equivalent load is F_E, the load factor K_L is defined by the equation

$$K_L = F_E / F \qquad \text{3-41}$$

The load factor is derived by setting the external work done by the equivalent load F_E on the equivalent system equal to the external work done by the actual load F on the actual element deflecting to the assumed deflected shape.

For a structure with distributed loads;

$$WD = F_E \delta_{\max} = \int_0^L p(x)\delta(x)dx \qquad \text{3-42a}$$

where

δ_{max} = *maximum deflection of actual structure*
$p(x)$ = *distributed load per unit length*
$\delta(x)$ = *deflection at any point of actual structure*
L = *length of structure*

rearranging terms

$$F_E = \int_0^L p(x)\phi(x)dx \qquad \text{3-42b}$$

where

$$\phi(x) = \delta(x)/\delta_{max} \qquad \text{3-43}$$

and is called the shape function.

NOTE. The shape function, $\phi(x)$ is different for the elastic range and the plastic range and therefore the load factor, K_L, will be different.

For example; the shape factor for a simply supported beam with a uniformly distributed load, in the elastic range is defined as

$$\phi(x) = (16/5L^4)(L^3x - 2Lx^3 + x^4) \qquad 3\text{-}44$$

while for the plastic range

$$\phi(x) = 2x/L \qquad x < L/2 \qquad 3\text{-}44b$$

For a structure with concentrated loads

$$WD = F_e\delta_{\max} = \sum_{r=1}^{i} F_r\delta_r \qquad 3\text{-}45a$$

Where

F_r = *rth concentrated load*
δ_r = *deflection at load r*
i = number of concentrated loads

rearranging terms

$$F_E = \sum_{r=1}^{i} F_r\phi_r \qquad 3\text{-}45b$$

where the shape factor is defined as

$$\phi_r = \sum_{r=1}^{i} \delta_r / \delta_{\max} \qquad 3\text{-}46$$

Again there is a K_L for the elastic range and a K_L for the plastic range. However, for a single concentrated load located at the point of maximum deflection (i.e. the center of a simply supported or fixed-fixed beam, or the end of a cantilever beam) ϕ_r is equal to one for both the elastic and plastic ranges and therefore K_L is equal to one for both ranges.

Values for K_L for one-way elements are presented in Table 3-12 (+). Equation 3-41 through 3-46 were used to calculate these values. An example calculating K_L is shown in Appendix A.

3-17.2.2 Mass Factor.

The mass factor is the design or transformation factor by which the total distributed mass of an element is multiplied to obtain the equivalent lumped mass of the equivalent single-degree-of-freedom system. If the total mass of the actual element is M and the mass of the equivalent system is M_E, the mass factor K_M is defined by the equation

$$K_M = M_E / M \qquad 3\text{-}47$$

K_M can be obtained by setting the kinetic energy of the equivalent system equal to the kinetic energy of the actual structural component as determined from its deflected shape.

For a structure with continuous mass

$$K_E = \tfrac{1}{2} M_E (\omega \delta_{\max})^2 = \tfrac{1}{2} \int_0^L m(x)[\omega \delta(x)]^2 dx \qquad 3\text{-}48a$$

where

ω = *natural circular frequency*
m(x) = distributed mass per unit length

rearranging terms

$$M_E = \int_0^L m(x) \phi^2(x) dx \qquad 3\text{-}48b$$

where the shape function $\phi(x)$ is based on the deflected shape of the element due to the applied loading and not to the distribution of the mass. Since the deflected shape of the element is different for the elastic and plastic ranges, $\phi(x)$, and therefore K_M, will also be different.

Using Equations 3-47 and 3-48, values for K_M were calculated for one-way elements with constant mass. These values are shown in Table 3-12 (+).

For a concentrated mass system,

$$K_E = \tfrac{1}{2} M_E \left(\omega \delta_{\max}\right)^2 = \tfrac{1}{2} \sum_{r=1}^{i} M_r \left(\omega \delta_r\right)^2 \qquad \text{3-49a}$$

where
M_r = *rth mass*
δ_r = *deflection of mass r*
i = number of lumped masses

rearranging terms

$$M_E = \sum_{r=1}^{i} M_r \phi_r^{\,2} \qquad \text{3-49b}$$

An example of calculations for finding K_M can be found in Appendix 3A.

3-17.2.3 Resistance Function.

The resistance factor is the design factor by which the resistance of the actual structural element must be multiplied to obtain the resistance of the equivalent single-degree-of-freedom system. To obtain the resistance factor, it is necessary to equate the strain energy of the structural element, as computed from the assumed deflection shape, and the strain energy of the equivalent single-degree-of-freedom system. If the computed total resistance of the structural element is R and the equivalent total resistance of the equivalent system is R_E, then the resistance factor is defined by the equation

$$K_R = R_E / R \qquad \text{3-50}$$

Since the resistance of an element is the internal force tending to restore the element to its unloaded static position, it can be shown that the resistance factor K_R must always equal the load factor K_L.

3-17.3 Load-Mass Factor.

The load-mass factor is a factor formed by combining the two basic transformation factors, K_L and K_M. It is merely the ratio of the mass factor to the load factor, and it is convenient since the equation of motion may be written in terms of that factor alone. The equation of motion of the actual system is given as

$$F - R = Ma \qquad \text{3-51}$$

and for the equivalent system

$$K_L F - K_L R = K_M Ma \qquad 3\text{-}52a$$

which can be re-written as

$$F - R = (K_M / K_L) Ma \qquad 3\text{-}52b$$

or

$$F - R = K_{LM} Ma = M_e a \qquad 3\text{-}52c$$

where

$$K_{LM} = \text{load-mass factor} = K_M / K_L \qquad 3\text{-}53$$

and

M_e = *effective total mass of the equivalent system*

when expressed in terms of the unit area of the element, Equation 3-52c can be written as

$$f - r = K_{LM} ma = m_e a \qquad 3\text{-}54$$

Values of load, mass and load-mass factors are presented in Table 3-12 (+). Equation 3-53 was used to calculate the load mass factor.

Instead of computing the several factors above, the load-mass factors in the elastic and elasto-plastic ranges can be determined by relating the primary mode of vibration of the member to that of an equivalent single-degree-of-freedom system. In the plastic range, it can be assumed that neither the moment, nor the curvature, changes between the plastic hinges under increasing deflection. This assumption can be used to evaluate the effective plastic mass as follows:

In Figure 3-43 (+), a portion of a two-way element bounded by the support and the yield line is shown. The equation of angular motion for this section is

$$\Sigma M = I_m \Theta'' \qquad 3\text{-}55$$

where

ΣM = *summation of moments*
I_m = *mass moment of inertia about the axis of rotation*
Θ'' = *angular acceleration*

Substituting in equation

$$Fc - (\Sigma M_N + \Sigma M_p) = (I_m / L_1)a \qquad 3\text{-}56a$$

where *a* is the acceleration. Dividing through by *c*

$$F - (\Sigma M_N + \Sigma M_p)/c = (I_m / cL_1)a \qquad 3\text{-}56b$$

Since the second term is the resistance *R*

$$F - R = (I_m / cL_1)a = M_e a \qquad 3\text{-}56c$$

and the load-mass factor K_{LM} for the sector shown is

$$K_{LM} = I_m / cL_1 M \qquad 3\text{-}57$$

where *c* is the distance from the resultant applied load to the axis of rotation, L_1 is the total length of the sector normal to the axis of rotation and *M* is the total mass of the sector.

When the element is composed of several sectors, each sector must be considered separately and the contributions then summed to determine the load-mass factor for the entire element.

$$K_{LM} = \Sigma(I_m / cL_1)/M \qquad 3\text{-}58$$

For elements of constant depth and, therefore, of constant unit mass, the above equation can be written in terms of the area moment of inertia I and the areas *A* of the individual sectors.

$$K_{LM} = \Sigma(I/cL_1)/A \qquad 3\text{-}59$$

Table 3-13 (+) gives the load-mass factors for the elastic and elasto-plastic response ranges for various two-way elements. The values given in the table apply for two-way elements of uniform thickness and supported as indicated. Also if there are openings in the element, they must be compact in shape and small in area compared to the total area of the element.

Figure 3-44 (+) gives the load-mass factors for the plastic response of various two-way elements. The load-mass factors are a junction of support condition and yield line location. These two-way elements must conform to the following limitations:

(1) Element must be of constant thickness.

(2) Opposite support must provide the same restraint so that a symmetrical yield line pattern occurs.

(3) Any openings must be compact in shape and small in area compared to the total area of the element.

3-17.4 Natural Period of Vibration.

To determine the maximum response of a system either by numerical methods or design charts (both methods are described in Section 3-19), the effective natural period of vibration is required. This effective natural period of vibration, when related to the duration of a blast loading of given intensity and a given structural resistance, determines the maximum transient deflection X_m of the structural element.

The effective natural period of vibration is

$$T_n = 2\pi(m_e/K_E)^{1/2} = 2\pi(K_{LM}m/K_E)^{1/2} \qquad 3\text{-}60$$

where

m_e = *the effective unit mass*
K_E = *the equivalent unit stiffness of system*

The values used for the effective mass and stiffness for a particular element depends on the allowable maximum deflection. When designing for completely elastic behavior, the elastic stiffness is used. In all other cases the equivalent elasto-plastic stiffness, K_E, is used. The elastic value of the effective mass is used for the elastic range, while in the elasto-plastic range the effective mass is the average of the elastic and elasto-plastic values. For small plastic deflections ($\Theta \leq 2°$), the value of the effective mass is equal to the average of the plastic value and the equivalent elastic value. The plastic effective mass is used for large plastic deflections.

Figure 3-42 Typical Single-Degree-of-Freedom System

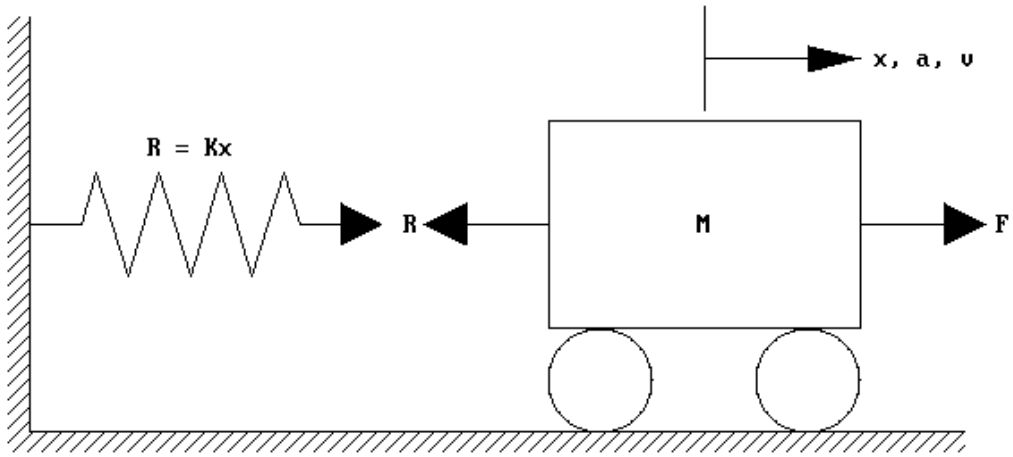


Figure 3-43 Determination of Load-Mass Factor in the Plastic Range

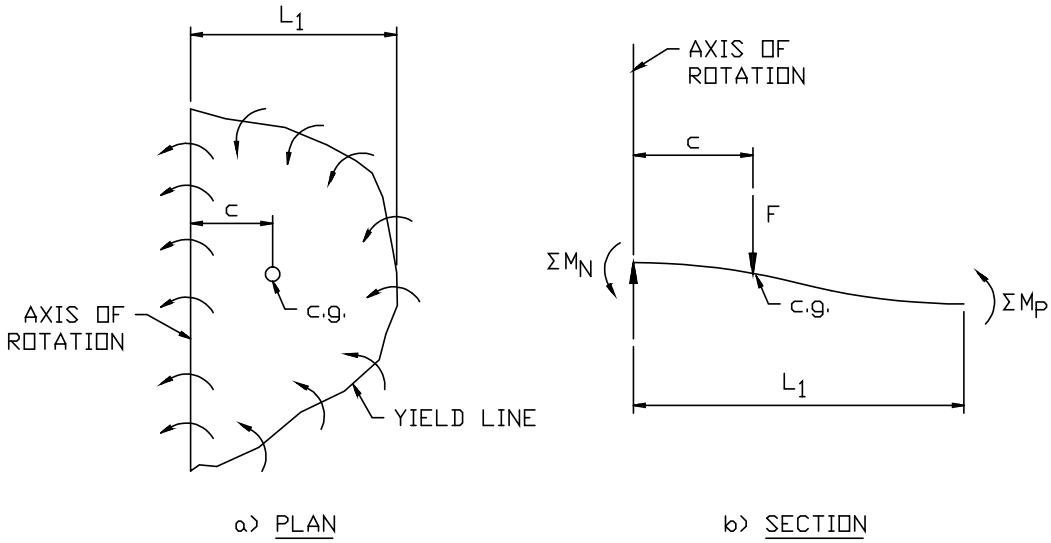


Figure 3-44 Load-Mass Factors in Plastic Range for Two-Way Elements

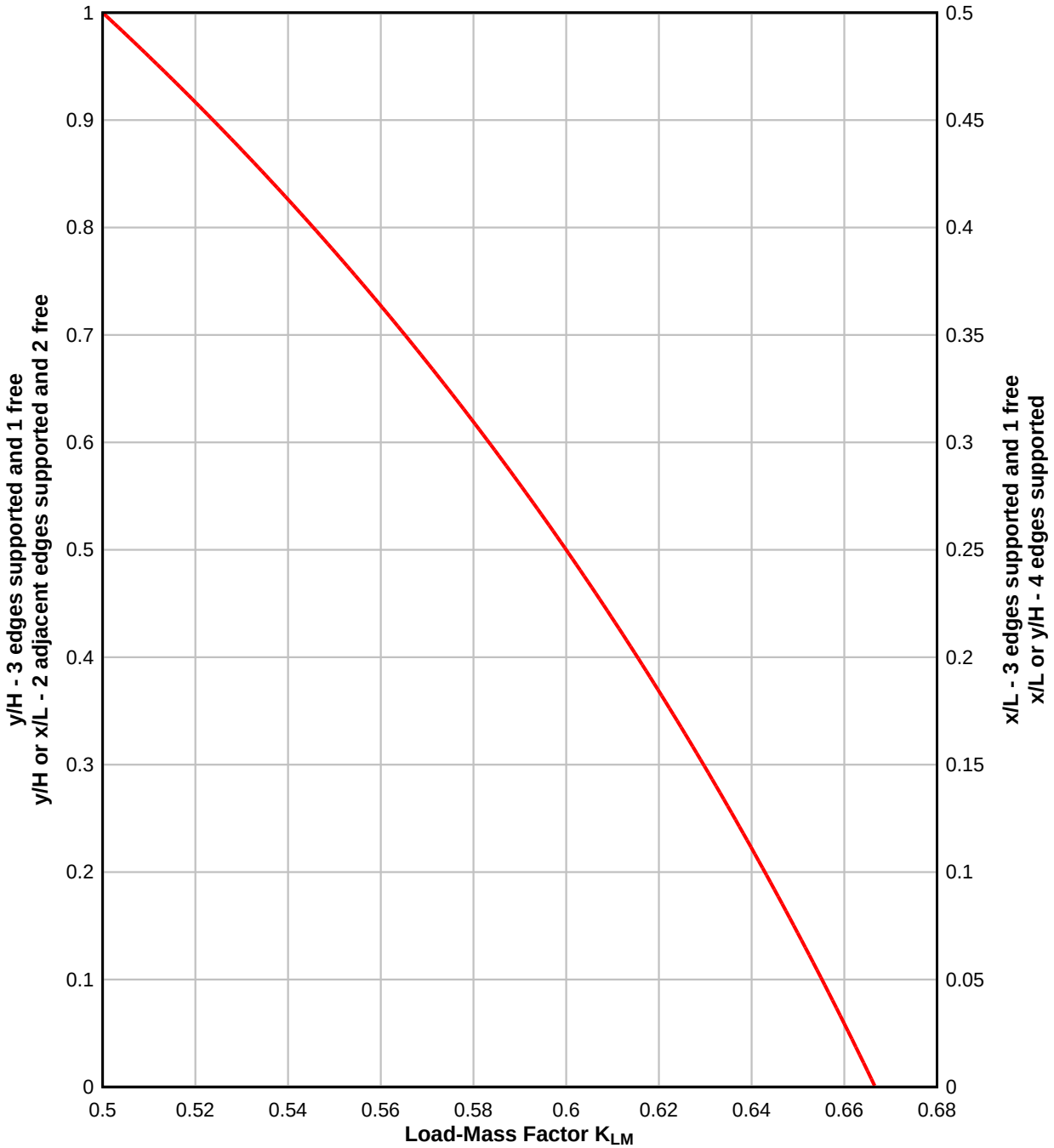


Table 3-12 Transformation Factors for One-Way Elements

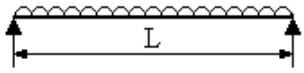
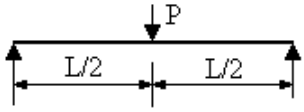
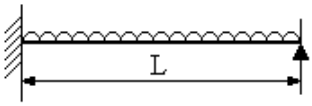
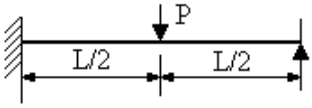
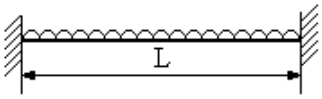
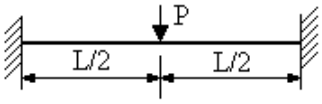
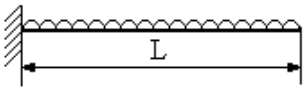
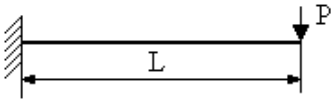
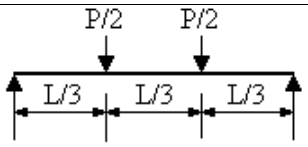
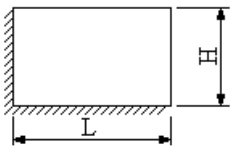
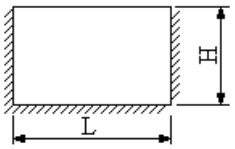
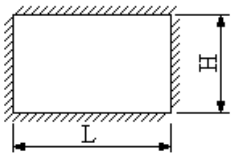
Edge Conditions and Loading Diagrams	Range of Behavior	Load Factor K_L	Mass Factor K_M	Load-Mass Factor K_{LM}
	Elastic Plastic	0.64 0.50	0.50 0.33	0.78 0.66
	Elastic Plastic	1.0 1.0	0.49 0.33	0.49 0.33
	Elastic Elasto-Plastic Plastic	0.58 0.64 0.50	0.45 0.50 0.33	0.78 0.78 0.66
	Elastic Elasto-Plastic Plastic	1.0 1.0 1.0	0.43 0.49 0.33	0.43 0.49 0.33
	Elastic Elasto-Plastic Plastic	0.53 0.64 0.50	0.41 0.50 0.33	0.77 0.78 0.66
	Elastic Plastic	1.0 1.0	0.37 0.33	0.37 0.33
	Elastic Plastic	0.40 0.50	0.26 0.33	0.65 0.66
	Elastic Plastic	1.0 1.0	0.24 0.33	0.24 0.33
	Elastic Plastic	0.87 1.0	0.52 0.56	0.60 0.56

Table 3-13 Load-Mass Factors in the Elastic and Elasto-Plastic Ranges for Two-Way Elements

Support Conditions		Value of L/H	Elastic and Elasto-Plastic Ranges (Support Conditions)				
			All Supports Fixed	One Support Simple Other Supports Fixed	Two Supports Simple Other Supports Fixed	Three Supports Simple Other Supports Fixed	All Supports Simple
Two adjacent edges supported and two edges free		ALL	0.65	0.66	-------	-------	0.66
Three edges supported and one edge free		$L/H < 0.5$	0.77	0.77	0.79	– – – – –	0.79
		$0.5 \le L/H \le 2$	$0.65 - 0.16\left(\frac{L}{2H} - 1\right)$	$0.66 - 0.144\left(\frac{L}{2H} - 1\right)$	$0.65 - 0.186\left(\frac{L}{2H} - 1\right)$	– – – – –	$0.66 - 0.175\left(\frac{L}{2H} - 1\right)$
		$L/H \ge 2$	0.65	0.66	0.65	– – – – –	0.66
Four edges supported		$L/H = 1$	0.61	0.61	0.62	0.63	0.63
		$1 \le L/H \le 2$	$0.61 + 0.16\left(\frac{L}{H} - 1\right)$	$0.61 + 0.16\left(\frac{L}{H} - 1\right)$	$0.62 + 0.16\left(\frac{L}{H} - 1\right)$	$0.63 + 0.16\left(\frac{L}{H} - 1\right)$	$0.63 + 0.16\left(\frac{L}{H} - 1\right)$
		$L/H \ge 2$	0.77	0.77	0.78	0.79	0.79

DYNAMIC ANALYSIS

3-18 INTRODUCTION.

Structural elements must develop an internal resistance sufficient to maintain all motion within the limits of deflection prescribed for the particular design. The load capacity of the member depends on the peak strength developed by the specific member (see Chapters 4 and 5) and on the ability of the member to sustain its resistance for a specific though relatively short period of time. This section describes the methods used for the analysis of structural elements subjected to dynamic loads, and these elements are divided into three groups, namely: (1) elements which respond to the pressure only (low pressure range), (2) elements which respond to pressure-time relationship (intermediate-pressure design range) and (3) elements which respond to the impulse which corresponds to the high pressure design range.

The method of analysis is different for the groups of elements. Those elements that respond to pressure only (this is still a pressure-time relation) and those that respond to pressure-time relationship may be analyzed using either numerical methods or design charts, while elements that respond to the impulse are analyzed using either design charts for large deflection or an impulse method for designs with limited deflections.

The method of analysis employing numerical techniques provides a solution that is obtained by a step-by-step integration, and is generally applicable for any type of load and resistance function. This method of analysis is presented in this section. Also presented is the result of a systematic analysis of single-degree dynamic systems for several idealized loadings plotted in nondimensional design charts.

3-19 ELEMENTS WHICH RESPOND TO PRESSURE ONLY AND PRESSURE-TIME RELATIONSHIP.

3-19.1 General.

To analyze these elements, the true magnitudes for the pressure-time relationship of the applied blast loads must be known. The determination of the dynamic response of these systems is accomplished using numerical techniques or design charts which relate the dynamic properties of the element (natural period of vibration, resistance, and deflection) to those of the blast overpressures.

3-19.2 Analysis By Numerical Methods.

The numerical method of analysis involves a step-by-step integration procedure, starting at zero time, when displacement and the velocity of the system are presumably known. The time scale is divided into several discrete intervals, and one progresses by successively extrapolating the displacement from one time station to the next. As the time interval in the sequence of time is reduced, i.e., as the number of discrete intervals is increased, the accuracy of the numerical method is improved.

3-19.2.1 Single-Degree-of-Freedom Systems.

As stated previously, a single degree of freedom system is one in which only one coordinate is essential to define its motion. The equation of motion for the single-degree-of-freedom system shown in Figure 3-42 (+) can be expressed as:

$$F - kx - cv = Ma \qquad (3\text{-}61)$$

where c = damping constant

There are several methods that can be used to numerically integrate Equation 3-61, but the two procedures applied to this problem will be the average acceleration, and the acceleration-impulse extrapolation methods.

3-19.2.1.1 Average Acceleration Method.

In the average acceleration method, the velocity and displacement at any time t are expressed as

$$v_t = v_{t-1} + 1/2\,(a_t + a_{t-1})\Delta t \qquad (3\text{-}62)$$

$$x = x_{t-1} + 1/2\,(v_t + v_{t-1})\,\Delta t \qquad (3\text{-}63)$$

Substituting Equation 3-62 into Equation 3-63,

$$x = x_{t-1} + v_{t-1}\,\Delta t + 1/4\,(a_t + a_{t-1})\,\Delta t^2 \qquad (3\text{-}64)$$

Substituting Equations 3-62 and 3-63 into Equation 3-61, we have

$$F - k\,[x_{t-1} + 1/2(v_t + v_{t-1})\Delta t] - c[v_{t-1} + 1/2\,(a_t + a_{t-1})\Delta t] = Ma \qquad (3\text{-}65)$$

Equation 3-65 can be simplified to

$$a = \frac{1}{m + \frac{1}{2}c\Delta t + \frac{1}{4}k\Delta t^2}\left[F - k\left(x_{t-1} + v_{t-1}\Delta t + \frac{1}{4}a_{t-1}\Delta t^2\right) - c\left(v_{t-1} + \frac{1}{2}a_{t-1}\Delta t\right)\right] \qquad (3\text{-}66)$$

The integrating procedure can be summarized as follows:

Step 1. At t = 0: Compute: a_o using Equation 3-61 and specified values for $x_o(t = 0)$, $v_o(t = 0)$, and $F(t = 0)$.

Step 2. Increment time: $t = t + \Delta t$

Step 3. At $t = t + \Delta t$: Compute a ($t = t + \Delta t$) using Equation 3-66, v ($t = t + \Delta t$) using Equation 3-62 and x ($t = t + \Delta t$) using Equation 3-63.

Step 4. Repeat steps 2 and 3 until some specified time or until the maximum displacement is reached.

It should be noted that if x (t = 0) and v (t = 0) are zero, then the system will not move as long as F (t = 0) is zero; however, if F (t = 0) is not zero, Equation 3-66 will give an acceleration and motion will start. Thus the system of equation is self-starting and requires no special starting provisions.

The procedure outlined above for an elastic single-degree-of-freedom system can be easily extended to accommodate elastic-plastic behavior. To do so, Equation 3-61 is re-written to include the restoring force R which replaces the spring restoring force kx, Equation 3-61 becomes

$$F - R - cv = ma \qquad 3\text{-}67$$

Substituting Equations 3-62 and 3-63 into Equation 3-67, the following equation for acceleration is obtained:

$$a_t = \frac{1}{m + \frac{(c\Delta t)}{2}}\left[F - R - c\left[v_{t-1} + \Delta t a_{t-1}/2\right]\right] \qquad 3\text{-}68$$

Unlike Equation 3-66, Equation 3-68 has a non-linear term R, and it depends on the displacement x at time t. Therefore, instead of using the direct integration approach as in the previous case, a predictor-corrector method is utilized. Briefly, the displacement x at time t is estimated (predicted) and then corrected and convergence of this procedure can be obtained in a single iteration if the value of Δt is small enough. The step-by-step procedure is outlined as follows:

Step 1. At t = 0: Compute at ($t = t_0$) from Equation 3-67 and the initial conditions.

Step 2. Increment time: $t = t + \Delta t$

Step 3. At $t = t + \Delta t$: Set $a_t = a_{t-1}$ (t - 1 = 0, initially)

Step 4. Compute v_t and x_t from Equations 3-62 and 3-63

Step 5. Compute R

Step 6. Compute a_t from Equation 3-68

Step 7. If you are in the predicting pass, return to Step 4, if in the correcting pass, set $x_{t-1} = x_t$, $v_{t-1} = v_t$, $a_t = a_{t-1}$ and go to Step 2.

3-19.2.1.2 Acceleration Impulse Extrapolation Method.

Suppose the acceleration of the system is defined by Figure 3-45a (+). The acceleration-impulse extrapolation method assumes that the actual acceleration curve can be replaced by a series of equally spaced impulses occurring at t_0, t_1, t_2,..., t_n, as shown in Figure 3-45b.

The magnitude of the acceleration impulse at t_n is given by

$$I(t_n) = a_n(\Delta t) \qquad 3\text{-}69$$

where $t - t_1 - t_0 = t_2 - t_1 =... = t_n - t_{n-1}$. This is shown in Figure 3-45b (+). Since an impulse is applied at t_n, there is a discontinuity in the value of velocity at t_n. In the time interval from t to t_{n-i}, the velocity is constant and the displacement varies linearly with time. The velocity and displacement thus obtained are shown in Figure 3-45c (+) and Figure 3-45d (+).

Suppose t_n^- and t_n^+ indicate the time immediately before and after the application of the impulse at t_n, and let v_n^- and v_n^+ indicate respectively the velocity at t_n^- and t_n^+; these two velocities are related by the following equation:

$$v_n^+ = v_n^- + a_n(\Delta t) \qquad 3\text{-}70$$

The relationship between x_{n-1} and x_n, and between x_n and x_{n+1} are given by:

$$x_n - x_{n-1} = v_n^-(\Delta t) \qquad 3\text{-}71a$$

$$x_{n+1} - x_n = v_n^+(\Delta t) \qquad 3\text{-}71b$$

Combining Equations 3-70 and 3-71, the three successive displacements are related by:

$$x_{n+1} = 2x_n - x_{n-1} + a_n(\Delta t)^2 \qquad 3\text{-}72$$

This is the basic recurrence formula for the acceleration impulse extrapolation method. Once the values of x at t_{n-1} and t_n are known, the value at t_{n+1} can be directly computed without resorting to a trial and error procedure.

It is necessary, however, to use a special procedure in the first time interval because, at $t = 0$, no value of x_{n-1} is available. Two different procedures may be used. The first assumes the acceleration varies linearly up to the first time station, in which case, the displacement of the system at that time can be expressed as:

$$x_1 = (1/6)(2a_0 + a_1)(\Delta t)^2 \qquad 3\text{-}73$$

The second procedure assumes that the acceleration is constant during the first time interval and is equal to the initial value. This assumption results in the following expression for x_1:

$$x_1 = (1/2)a_0(\Delta t)^2 \qquad 3\text{-}74$$

It should be noted that Equation 3-73 has to be solved by trial and error since a_1 depends on x_1. This trial-and-error procedure can be avoided by taking the value of a_1 to be $f(t)/m$ instead of the exact value of $[f(t_1) - R(t_1)]/m$. In Figure 3-46a (+) if $a_o' = 0$, a_o is equal to $a_o'/6$ and in Figure 3-46b (+) if a_o and a_1 are approximately equal to each other, the value $a_o'/2$ may be used for a_o. The recurrence formula is directly applicable for the evaluation of $x_2, x_3, \ldots, x_{n+1}$ whenever the acceleration is a continuous function. When there is a discontinuity in the acceleration, this equation can still be used but not before some modifications are made to reflect this discontinuity. In Figure 3-46a there is a discontinuity at t_4 which occurs at the end of the time interval Δt. Under this condition, the value of a_n used in the numerical procedure is the average value at discontinuity, namely $1/2\ (a_4' + a_4'')$ for a_4. In Figure 3-46b the discontinuity occurs within time interval, t. The correct value for a_3 in this procedure is:

$$a_3 = (1/2)[a_3 + a_3'' + (a_3' - a_3'')\ (\Delta t'/\Delta t)^2] \qquad 3\text{-}75$$

When there are more than two discontinuities, this procedure becomes cumbersome and it is more convenient to replace the given acceleration by a smooth curve. Equation 3-73 must be used if there is zero force (and hence zero acceleration) at zero time, for in no other way can x_1 be determined. If acceleration at $t = 0$ is not zero, Equation 3-74 may be used without appreciable error, provided the force does not change greatly in the first interval.

The tedious method of numerical analysis is made somewhat easier if the computation procedure is set up as shown in Table 3-14 (+). In the first time interval, the value used for the acceleration, a_o, depends on the forcing function. If the value of the forcing function is zero at time zero, then a_o is taken as one-sixth of a_1, where a, is the ratio of the value of the forcing function at t, to the mass of the system $[a_o = f(t_1)/6m]$. When the value of the forcing function is not zero at time zero, and if the values of the forcing

function at times $t=0$ and $t=t_1$ are approximately equal, then a_o may be taken as $(P_o-R_o)/2$. The recurrence formula (Equation 3-72) is used in the other intervals.

It may be necessary during the computational procedure, to increase the value of t so as to reduce the number of time intervals. In Figure 3-47 (+), for example, the forcing function varies linearly after time j. For the next time station $(j + 1)^{st}$, the value of Δt, can be increased ($\Delta t_2 = 2\Delta t_1$ for example) without introducing any errors in the computations. In such cases, caution has to be exercised when using the recurrence formula. In Table 3-14 (+), the value of Δt changes after the jth step, to $\Delta t_2 = 2\Delta t_1$. In the $(j + 1)^{st}$ step, x_{n-1} should be the value of x for the $(j-1)^{nd}$ step and x_n will be the value of x_{n+1} for the $(j-1)^{st}$ step.

3-19.2.2 A Two-Degree-of-Freedom-System.

A two-degree-of-freedom system is shown in Figure 3-48 (+) where the coordinates defining the configuration of the system are X_1 and X_2. The equation of motion for each of the two masses can be expressed as follows:

$$F_1 + R_2 - R_1 = M_1 a_1 \qquad 3\text{-}76a$$

$$F_2 - R_2 = M_2 a_2 \qquad 3\text{-}76b$$

Equation 3-76 can be rewritten as:

$$a_1 = F_1/M_1 + R_2/M_1 - R_1/M_1 \qquad 3\text{-}77a$$

$$a_2 = F_2/M_2 - R_2/M_2 \qquad 3\text{-}77b$$

The integration procedures described for a single-degree-of-freedom system can also be applied to two-degrees-of-freedom systems. In the average acceleration procedure, if the equations are placed in the same form as Equation 3-61, i.e., if the acceleration at time t are written in terms of displacements and velocities at time $t - \Delta t$, then two equations are obtained which must be solved simultaneously for a_1 and a_2. In the other numerical integration procedure, the recurrence formula (Equation 3-72) applies to each of the two displacements independently.

3-19.2.3 Damping.

The effects of damping are hardly ever considered in blast design because of the following reasons:

(1) Damping has very little effect on the first peak of response, which is usually the only cycle of response that is of interest.

(2) The energy dissipated through plastic deformation is much greater than that dissipated by normal structural damping.

(3) Ignoring damping is a conservative approach.

If damping has to be considered in an analysis, however, it should be expressed as some percentage of critical damping. For free vibration, this is the amount of damping that would remove all vibration from the system and allow it to return to its neutral position. Critical damping is expressed as

$$C_{cr} = 2\ kM \qquad 3\text{-}78$$

where

k = stiffness of the system
M = mass of the system

The damping coefficient, c, in Equations 3-61 and 3-67 is expressed as a percentage of critical damping, C_{cr}. For steel structures, c should be taken as $0.05C_{cr}$ and $0.01\ C_{cr}$ for reinforced concrete structures.

3-19.3 Design Charts for Idealized Loadings.

3-19.3.1 General.

The response of single-degree-of-freedom systems subjected to idealized blast loadings is presented in the form of non-dimensional curves. In order to utilize these response charts, both the blast loads (pressure - time history) and the resistance-deflection curve of the structural system are idealized to linear or bilinear functions. Methods for computing these idealized blast loads are given in Chapter 2 while the methods for computing the resistance-deflection functions as well as converting the actual system to an elastic or elasto-plastic single-degree-of-freedom system have been presented in previous sections of this chapter.

The response of a structural system subjected to a dynamic load is defined in terms of its maximum deflection X_m and the time t_m to reach this maximum deflection. The dynamic load is defined by its peak value P, duration T, and shape. The response of the single-degree-of-freedom system with elastic response is defined in terms of the dynamic load factor (DLF). The response of the single-degree-of-freedom system with elasto-plastic response is defined in terms of its ultimate resistance r_u, yield deflection X_E, and natural period T_N. Response charts relate the dynamic properties of the blast load (P and T) to those of the element (r, X, T_N), that is, X_m/X_E and t_m/T are plotted as a function of r_u/P and T/T_N. More information is provided in the following sections.

Response charts have been prepared for simplified loads as well as for the more complex bilinear loadings. The simplified loadings include triangular, rectangular, step load with finite rise time, triangular with rise time and sinusoidal pulse. The idealized triangular loading is utilized in the analyses of acceptor structures. These structures are subjected to the effects of unconfined explosions, such as free-air or surface bursts or

partially confined explosions in donor structures which are fully vented. On the other hand, idealized instantaneously applied or gradually applied flat top loads are usually encountered in the design of roof elements of acceptor structures. These structures are subjected to very long duration loads produced by very large explosive quantities. The triangular loading with a rise time is similar to the previously mentioned triangular load except that it is an equivalent loading produced by the blast traversing an element. The sinusoidal loadings is usually associated with the vibrational type of load rather than blast induced input. The bilinear loading is utilized in the analysis of containment structures which allow partial venting of an explosion and in the analysis of acceptor structures where reflected pressures clear rapidly around the structure.

The effects of damping have not been included in the preparation of the response charts. In the design of the blast resistant structures, the first peak of response is usually the only cycle of response that is of interest since the maximum resistance and deflection is attained in that cycle. Damping has very little effect on this first peak and consequently, neglecting damping has negligible effects on maximum response calculations.

3-19.3.2 Maximum Response of Linear Elastic System to Simplified Loads.

To obtain the response of a linear elastic system, it is convenient to consider the concept of the dynamic load factor. This factor is defined as the ratio of the maximum dynamic deflection to the deflection which would have resulted from the static application of the peak load *P*, which is used in specifying the load-time variation. Thus the dynamic load factor (*DLF*) is given by:

$$DLF = X_m / X_s \qquad \text{3-79a}$$

where

X_s = *static deflection or, in other words, the displacement produced in the system when the peak load is applied statically.*
X_m = *maximum dynamic deflection*

Since deflections, spring forces, and stresses in an elastic system are all proportional, the dynamic load factor may be applied to any of these to determine the ratio of dynamic to static effects. Therefore, the dynamic load factor may be considered as the ratio of the maximum resistance attained to the peak load or:

$$DLF = r/p \qquad \text{3-79b}$$

where

r = *maximum dynamic resistance*
p = *peak load used in specifying the load-time variation.*

For a linear elastic system subjected to a simplified dynamic load, the maximum response is defined by the dynamic load factor, *DLF* and maximum response time, t_m. The dynamic load factor and time ratio t_m/T are plotted versus the time ratio T/T_N for a triangular load, rectangular load, step load with finite rise time (T_r), triangular load with rise time, and sinusoidal pulse in Figure 3-49 through Figure 3-53.

In many structural problems only the maximum value of the *DLF* is of interest. For the most prevalent load case, namely, the triangular load as well as the rectangular and step load with rise time, the maximum value of the *DLF* is 2. This immediately indicates that all maximum displacements, forces, and stresses due to the dynamic load are twice the value that would be obtained from a static analysis for the maximum load *P*.

The above response charts apply for elastic systems. However, the charts can be applied to the entire elasto-plastic range if the actual resistance-deflection curve (two step system, three step system, etc.) is replaced by the equivalent elastic system where the equivalent elastic stiffness K_E and the equivalent elastic deflection X_E are obtained according to previously explained procedures (see Section 3-14).

In a typical design example, the pressure-time loading is calculated and idealized to one of the simplified loads defined by *P* and *T* or T_r. A structural member is assumed and its corresponding dynamic properties are calculated. For a completely elastic response, the values of r_e and T_N are calculated while for a response in the elasto-plastic range, r_u, X_E and T_N are obtained. It should be noted that for a response in the elasto-plastic range, the value of T_N is calculated using the effective mass which is an average of the elastic and elasto-plastic values. Knowing the ratio of T/T_N the dynamic load factor (*DLF*) and the time ratio can be read from the appropriate figures. The maximum resistance *r* attained by the structural member is calculated from the *DLF* and the response time is obtained from the time ratio. If the resistance r is greater than r_e for a completely elastic response in the elasto-plastic range, then the analysis is not valid and the procedure is repeated. The maximum deflection is obtained from the resistance *r* and the stiffness K_e or K_E.

3-19.3.3 Maximum Plastic Response of an Elasto-Plastic System to Simplified Loads.

An elasto-plastic system may have an elastic or plastic response depending upon the magnitude of the blast load. If the response is elastic, that is, the member attains a resistance r which is less than its ultimate resistance r_u, then the charts of the preceding section are used. The response charts presented in this section are only for the plastic response of members where the ultimate resistance r_u is attained.

The maximum plastic response of an elasto-plastic system subjected to a blast load is defined by the maximum deflection, X_m it attains and the time, t_m it takes to reach this deflection. The blast load is defined by its peak value P and duration T while the singe-degree-of-freedom system is defined by its ultimate resistance r_u, elastic deflection X_E and natural period T_N. A nondimensional response chart is constructed by plotting the ductility ratio X_m/X_E and the time ratio t_m/T as a function of r_u/P and T/T_N. Response charts are given for a triangular load, rectangular load, step load with finite rise time T_r and triangular load with rise time in Figure 3-54 through Figure 3-61. It should be noted that for the step load with finite rise time, the load is defined by the rise time T_r and, consequently, the response curves are plotted using T_r rather than T.

In a typical example, the pressure-time loading is calculated and idealized to one of the simplified loads defined by either P and T or P and T_r. A structural member is assumed and its corresponding dynamic properties (r_u, X_E, T_N) are calculated. Knowing the ratios of r_u/P and T/T_N (or T_r/T_N), the ductility ratio X_m/X_E and the time ratio t_m/T can be read from the appropriate figures. The maximum deflection X_m and response time t_m can readily be calculated. If the ductility ratio X_m/X_E or the maximum deflection X_m and corresponding response time t_m are unsatisfactory, the procedure is repeated.

It should be noted that the value of the natural period of vibration T_N used in conjunction with the response charts varies according to the magnitude of the ductility ratio X_m/X_E. For small plastic deformations (X_m/X_E less than 5), the calculations of T_N is based on an average of the equivalent elastic and plastic masses. Whereas, for larger plastic deformations (X_m/X_E greater than 5), the equivalent plastic mass is used to obtain T_N.

3-19.3.4 Maximum Plastic Response of an Elasto-Plastic System to Idealized Bilinear Loads.

Response charts have been prepared for bilinear loads in much the same manner as for simplified loads. However, four parameters are required to define the bilinear loading rather than two parameters which are required for the simplified loads. These additional parameters greatly increase the number of charts required for the rapid prediction of the dynamic response of an elasto-plastic system. However, the computational procedures remain comparatively simple.

A bilinear load is illustrated in Figure 3-62 (+). Four parameters are required to define this load shape, namely:

P = peak pressure of shock load (primary pulse)

C_1P = peak pressure of gas load (secondary pulse)

T = duration of shock load

C_2T = duration of gas load

It can be seen from Figure 3-62 (+) that the value of C_1 will always be less than 1 while the value of C_2 will always be greater than 1.

Response charts for the bilinear load are prepared in the same way as the simplified loads except that each chart is prepared for a given value of C_1 and C_2. The ductility ratio X_m/X_E versus T/T_N is plotted on each chart for various values of P/r_u, t_m/T_N and t_E/T (where t_E is the time to reach the maximum elastic deflection x_E). Therefore, each chart contains three families of curves. In addition, each chart contains one, two or three boundaries which are formed by symbols. These boundaries delineate regions of each chart where certain approximations are preferable to chart interpolation. These approximations involve modification of the bilinear load for the various regions. The loads considered for each of the regions are given in Figure 3-62 (+) while the boundaries for the various regions are defined in Figure 3-63 (+).

Numerous response charts are required for bilinear loads. Table 3-15 (+) lists the figure numbers of the response charts prepared for the selected values of C_1 and C_2. These response charts are presented in Figure 3-64 through Figure 3-266.

To use the response charts, the first step is to enter Table 3-15 (+) with the required values of C_1 and C_2. Locate the points in the table with coordinates C_1 and C_2. The number in the box containing the point is the appropriate figure number to use to solve the problem. If the point is not located in a box having a number, the two or, more frequently, four numbers bracketing the point are the appropriate figure numbers to use. Interpolation for the required values of C_1 and C_2 must be performed. A graphical and mathematical interpolation procedure is presented in subsequent sections.

In a typical design, a structural member is assumed and the idealized resistance function defined by r_u, X_E and K_E can be determined along with the natural period. As previously explained for simplified loads; the equivalent mass used to calculated T_N varies according to the amount of plastic deformation. Knowing the ratio of P/r_u and T/T_N, note if the intersection point corresponding to these parameters, is located in region A, B, C or D on the response chart(s) for the required values of C_1 and C_2. The boundaries for these regions are represented by a line of asterisks, solid circles, and solid squares, as illustrated in Figure 3-63 (+).

The final step in obtaining the solution depends on which region of the response chart(s) is applicable. These regions were established to reduce the amount of calculations required for a solution by eliminating, where possible, interpolation between charts. Except for one of the four regions, the actual bilinear blast load is replaced by a simplified load. Solution of the response for these simplified loads will predict a solution which is within 10 percent of the exact solution. Of course, the exact solution of the response for the structural member in these three regions can be obtained by using the required response charts and interpolating, where required, between charts.

3-19.3.4.1 Region A.

This region is defined as the area to the left of the solid circles on the response charts. If a chart does not have a line of solid circles, then region A does not exist. Figure 3-221 (+), Figure 3-222 (+) and Figure 3-223 (+) illustrate this case.

In region A the maximum dynamic response depends primarily upon the total impulse in the blast loading (area under the pressure-time curve). The actual pressure-time distribution does not significantly affect the maximum dynamic response because in these regions the durations T and C_2T are small in comparison to the response time, t_m of the structural member. In this region the response charts are not used and a solution is obtained by considering the modified loading shown in Figure 3-62a (+). This load shape yields the following equations:

$$\frac{X_m}{X_E} = \frac{1}{2} + \frac{\pi^2}{2}\left[\frac{P}{r_u}\frac{T}{T_n}F\right]^2 \qquad \text{3-80}$$

and

$$\frac{t_m}{T_n} = \frac{1}{2}F\frac{P}{r_u}\frac{T}{T_n} \qquad \text{3-81}$$

where

$$F = C_2 + \frac{C_2[1-C_1][1-C_2]}{C_2 - C_1} \qquad \text{3-82}$$

3-19.3.4.2 Region B.

This region is defined as the area in the chart to the left of the asterisks. If a chart has no line of asterisks, then region B does not exist. Figure 3-65 (+/+/+) illustrates the case where region B does not exist.

In region B the maximum dynamic response depends primarily upon the gas load which is described by C_1P and C_2T. The shock load described by P and T is neglected. This load condition is shown in Figure 3-62b (+). Therefore the solution is obtained from consideration of a single triangular load. The dynamic response is obtained from Figure 3-64 (+/+) which like Figure 3-54 (+) and Figure 3-55 (+) is for a triangular load and will yield the same results. When using Figure 3-64 it must be realized that the P and T used in the chart are actually C_1P and C_2T, respectively. In a typical design, enter Figure 3-64 with the normalized parameters, C_1P/r_u and C_2T/T_N, and read the solution, X_m/X_E, t_m/T_N, and t_E/C_2T.

Figure 3-63 (+) depicts region B as the area between the line of solid circles and the line of asterisks. It should be understood that the solution technique associated with region B (i.e., neglect the shock load and use Figure 3-64 (+/+)) applies everywhere to the left

of the line of asterisks, including region A. In other words, two solution techniques are available in region A.

3-19.3.4.3 Region D.

This region is defined as the area in the charts to the right of the line of solid squares. If a chart has no line of solid squares, then region D does not exist. Figure 3-69 (+/+/+) illustrates the case where region D does not exist.

In region D the maximum dynamic response depends primarily upon the shock load which is described by P and T. The gas load described by C_1P and C_2T is neglected. This load condition is shown in Figure 3-62d (+). Therefore, the solution is obtained from consideration of a single triangular load. Similar to region B, the dynamic response is obtained from Figure 3-64 (+/+) which is for a triangular load. Unlike region B, the parameters, P and T which describe the load are used in the figure. Therefore, in a typical design, enter Figure 3-64 with the normalized parameters P/r_u and T/T_N, and read the solution, X_m/X_E, t_m/T_N and $t_E/_T$.

3-19.3.4.4 Region C.

This is the region in the charts which do not meet the definitions of regions A, B and D. In most charts, region C is the area to the left of the line of solid squares and to the right of the line of asterisks, as illustrated in Figure 3-63 (+). Region C does not exist in some charts, such as Figure 3-97 (+/+/+) which have over lapping regions A and D.

In region C, both the shock and gas load must be considered. Replacement of the actual bilinear load with a simplified load, as done for the other regions, will yield an incorrect solution. Therefore, in this region the response charts must be used. If the required values of C_1 and/or C_2 do not correspond to the response chart values, interpolation between response charts will be required to obtain a solution. In a few cases one or two response charts are needed, however, in general four response charts are required for a solution.

3-19.3.4.5 Response Chart Interpolation.

Interpolation between four response charts will usually be required for region C. For regions A, B, or D, if conditions warrant an exact solution rather than the approximate solution usually used in these regions, interpolation between charts may be required. Either a graphical or mathematical interpolation procedure may be employed. The method selected depends upon personal choice. A brief description of each procedure is presented below and an example of each is given in Appendix A.

Graphical interpolation requires a sheet of log-log graph paper. A convenient size is 2 x 1 cycle with the single-cycle axis representing C_1 and C_2, and the two-cycle axis representing the desired parameter (X_m/X_E, t_m/T_N or t_E/T), called Y for ease of presentation. The appropriate figures to be used for a solution are obtained from Table 3-15 (+) for the required values of C_1 and C_2. The procedure will illustrate the interpolation between four figures since this is by far the usual case. For the values of

P/r_u and T/T_N corresponding to the structural system selected, determine the desired parameter Y for each of the four figures. Organize a table in the same format as Table 3-16 (+) and enter each figure number and corresponding value of C_1, C_2 and Y.

In the table, C_{11} and C_{21} are the values of C_1 and C_2, respectively, from Figure 1. Likewise, C_{12} and C_{22} are the values of C_1 and C_2, respectively, from Figure 2, etc. The symbol Y_1, is the desired parameter, such as X_m/X_E, which is read from Figure 1. The symbol Y_2 is the value read from Figure 2, etc. The interpolation is first performed for the required value of C_1 and then for the required value of C_2. That is, with C_{21} constant, graphically interpolate on the log-log paper between points (Y_1, C_{11}) and (Y_2, C_{12}) to find Y_a corresponding to C_1 and C_{21}, as shown on Figure 3-267 (+). Similarly, with C_{23} constant, graphically interpolate between (Y_3, C_{13}) and (Y_4, C_{14}) to find Y_b corresponding to C_1 and C_{23}, also shown in Figure 3-267. The values of Y_a and Y_b are recorded in Table 3-16 (+). Finally, with C_1 constant, graphically interpolate on the log-log paper between (Y_a, C_i) and (Y_b, C_{23}) to find Y corresponding to the required C_1 and C_2, as shown on Figure 3-267. The value of Y is the solution. Since there are three parameters to define the response of a structural, namely, X_m/X_E, t_m/T_N and t_E/T, the interpolation procedure is repeated three times, once for each parameter.

Mathematical interpolation requires the same initial steps as graphical interpolation. That is, the appropriate figures to be used for a solution are obtained from Table 3-15 (+) and the required parameters are determined and entered into Table 3-16 (+). Logarithmic equations are used to obtain the values of Y_a, Y_b and Y. The value of $\ln Y_a$ is obtained from:

$$\ln Y_a = \ln Y_1 + \frac{\ln(Y_2/Y_1)\ln(C_1/C_{11})}{\ln(C_{12}/C_{11})} \qquad \text{3-83}$$

and the value of $\ln Y_b$ is obtained from:

$$\ln Y_b = \ln Y_3 + \frac{\ln(Y_4/Y_3)\ln(C_1/C_{13})}{\ln(C_{14}/C_{13})} \qquad \text{3-84}$$

Using the values of $\ln Y_a$ and $\ln Y_b$; the value of $\ln Y$ is obtained from:

$$\ln Y = \ln Y_a + \frac{(\ln Y_b - \ln Y_a)\ln(C_2/C_{21})}{\ln(C_{23}/C_{21})} \qquad \text{3-85}$$

The desired parameter Y is then obtained from:

$$Y = e^{lnY} \qquad 3\text{-}86a$$

The above equations use natural logarithms. Common logarithms can be used to solve the above equations and then solve for Y using:

$$Y = 10^{logY} \qquad 3\text{-}86b$$

It should be noted that if C_2 is represented by a response chart, then only two charts will be involved, and only Equation 3-83 will apply.

3-19.3.4.6 Accuracy.

The prediction error is less than 10 percent for the approximate solutions obtained in regions A, B and D. This is true provided the recommended procedures are employed, that is, the actual load is replaced by the approximate loads as shown on Figure 3-62 (+) and the solution is obtained using the equations provided for region A and using Figure 3-64 (+/+) for regions B and D.

Exact solutions are obtained from the response charts if the required values of C_1 and C_2 correspond to those given in the charts. This is true for all four regions. Errors result from interpolation between the response charts. The prediction error in X_m/X_E for region C, where interpolation between charts is required, is less than 10 percent provided response charts bounded by the dashed or solid lines on Table 3-15 (+) are not used. The prediction error in X_m/X_E will range from 55 to 100 percent for solutions in region C, if the point (C_1, C_2) lies in the area bounded by the solid line in Table 3-15, and will range from 10 to 55 percent for the area bounded by the dashed line. If the solution involves charts from both sides of either the dashed or solid lines, the prediction error will range from 10 to 55 percent. The large interpolation error for these charts result from the big change in X_m/X_E for a small change in P/r_u which is peculiar to this chart.

It should be noted that the large errors described above will always be on the high side, that is, the predicted value of X_m/X_E will always be greater than the exact value. Hence, a conservative design will always result. In addition, it should be noted that the prediction error in t_m/T_N is about half the error in X_m/X_E.

While the errors produced from interpolation between the charts in Table 3-15 (+) bounded by the dashed and solid lines is large, the area in which they apply is small. As can be seen, region C is rather small on these charts. It is for points in this small area where interpolation must be performed. For the remaining areas (A, B and D), the approximate solutions may be used rather than interpolation. These approximate solutions will result in an error of less than 10 percent.

Solutions involving $0.920 < C_1 < 1.00$ and $C_2 \geq 100$ can result in very large errors if interpolating procedures are employed. In this region, the dynamic response is primarily due to the gas load. Therefore, Figure 3-64 (+/+) is used to obtain X_m/X_E for the gas

load. However, this value is too low and should be increased by 20 percent. The value of t_m/T_N corresponding to the increased value of X_m/X_E is then obtained from Figure 3-64.

3-19.3.5 Determination of Rebound.

In the design of elements which respond to the pressure only and pressure-time relationship, the element must be designed to resist the negative deflection or rebound which can occur after maximum positive deflection has been reached. The ratio of the required unit rebound resistance to the ultimate unit resistance r/r_u, such that the element will remain elastic during rebound is presented in Figure 3-268 (+) for a single-degree-of-freedom system subjected to a triangular loading function. Entering with ratios X_m/X_E and t/T_N previously determined for design, the required unit rebound resistance r^- can be read in terms of the originally designed ultimate unit resistance r_u. To obtain the rebound resistance for an element subjected to another form of load other than the triangular loading function, a time-history analysis such as the one described in Section 3-19 has to be performed.

It may be noted that if the loading is applied in a relatively short time compared to the natural period of vibration of the system, the required rebound resistance can be equal to the resistance in the initial design direction. When the loading is applied for a relatively long time, the maximum deflection is reached when the positive forces are still large and the rebound resistance is reduced.

3-20 ELEMENTS WHICH RESPOND TO IMPULSE.

3-20.1 General.

When an element responds to the impulse, the maximum response depends upon the area under the pressure time curve (impulse of blast loading). The magnitude and time variation of the pressure are not important. The response charts presented in Section 3-19, which are based on pressure-time relationship are therefore not required for these problems. Instead, the element resistance required to limit the maximum deflection to a specific value is obtained through the use of a semigraphical method of analysis.

Consider the pressure-time and resistance-time functions shown in Figure 3-269 (+). The resistance curve depicted is for a two-way element with a resistance-deflection function having a post-ultimate range. From Newton's equation of motion it can be shown that the summation of the areas (considering area A as positive and area B as negative) under the load-time curves up to any time t_a divided by the corresponding effective masses is equal to the instantaneous velocity of that time:

$$v_a = \int_0^{t_a} \frac{(f - r)dt}{m_e} \qquad 3\text{-}87$$

The displacement at time t_a is found by multiplying each differential area divided by the appropriate effective mass by its distance to t_a and summing the values algebraically:

$$X_a = \int_0^{t_a} \frac{(f-r)}{m_e}[t_a - t]dt \qquad 3\text{-}88$$

In each range the mass is the effective plastic mass:

Time Interval	Resistance	Effective Mass
$0 \le t \le t_1$	r_u	$m_u = [K_{LM}]\, m_u$
$t_1 \le t \le t_m$	r_{up}	$m_{up} = [K_{LM}]\, m_{up}$

Time t_1 is the time at which the partial failure deflection X_1 occurs, and time t_m is the time at which maximum deflection X_m is reached ($X_m < X_u$).

For an element to be in equilibrium at its maximum deflection, its impulse capacity must be numerically equal to the impulse of the applied blast load. With the use of the foregoing equations, the expressions which define the motion and capacity of elements subjected to impulse type loads, can be defined. These expressions are presented for both large and limited deflection criteria. This criteria varies for the different materials used in protective design. The criteria for each material is obtained from the chapter that describes the design procedures for that material.

Case 1 - large deflections.

Utilizing Equation 3-88 and by taking moments of the areas under the pressure-time and resistance-time curves (Figure 3-269 (+)) about time t_m, assuming that the unit blast impulse i_b is applied instantaneously at time t=0, and that time to reach yield t_y is also close to zero the expression for the maximum deflection is

$$X_m = \frac{i_b t_m}{m_u} - \frac{r_u t_1[t_m - t_1/2]}{m_u} - \frac{r_{up}[t_m - t_1]}{2m_{up}}[t_m - t_1] \qquad 3\text{-}89$$

If moments of the areas are taken about t_1, then the deflection at partial failure X_1, is

$$X_1 = \frac{i_b t_1}{m_u} - \frac{r_u t_1^{\,2}}{2m_u} \qquad 3\text{-}90$$

Using Equation 3-87 and summing the areas of t_m and recognizing that the instantaneous velocity at t_m equals zero.

$$\frac{i_b}{m_u} - \frac{r_u t_1}{m_u} - \frac{r_{up}\left[t_m - t_1\right]}{m_{up}} = 0 \qquad \text{3-91}$$

Solution of the above three simultaneous equations is accomplished by solving Equation 3-91 for t_m and substituting this expression into Equation 3-89, and solving Equation 3-90 for t_1 and substituting this expression into the modified Equation 3-89. After continuing and rearranging terms, the general response equation becomes

$$\frac{i_b^{\,2}}{2m_u} = r_u X_1 + \frac{m_u}{m_{up}} r_{up}\left(X_m - X_1\right) \qquad \text{3-92}$$

The left side of this equation is simply the initial kinetic energy resulting from the applied blast impulse and the right side is the modified potential energy of the element. The modification is required since the above analysis requires the use of two equivalent dynamic systems (before and after time t_1). The modification factor m_u/m_{up} equates the two dynamic systems. If the effective mass in each range was the same, m_u/m_up would equal one and the right side of the expression would be r_uX_m which is the potential energy.

For one-way elements which do not exhibit the post-ultimate resistance range, or for two-way panels where the maximum deflection X_m is less than X_1, Equation 3-92 becomes

$$\frac{i_b^{\,2}}{2m_u} = r_u X_m \qquad \text{3-93}$$

The above solutions are valid only for what is considered large deflection design since the variation of resistance with deflection in the elasto-plastic range has been ignored. This limitation is based on the assumption that the time to reach yield t_y and the duration of the impulse t_o are small in comparison to t_m.

Case 2 - limited deflections.

For elements which respond to the impulse with limited deflections where the time to reach maximum deflection t_m is greater than three times the duration t_o of the load, but where the support rotations are equal to or less than the established criteria, the elasto-plastic range behavior of the element must be accounted for in determining the overall response of the element to the applied blast load. For this case, Equation 3-92 becomes

$$\frac{i_b^{\,2}}{2m_a} = \frac{r_u X_E}{2} + \frac{m_a}{m_u} r_u \left(X_m - X_E\right) \qquad 3\text{-}94$$

where m_a is the average of the effective elastic and plastic masses and X_E the equivalent yield deflection.

When the response time t_m of an element is less than three times the load duration t_o, the element will respond to the pressure pulse rather than to the impulse alone. In this case the response of the element may be obtained through the use of a response chart considering a simplified pressure pulse as outlined in Chapter 2. However, if the element's maximum deflection is greater than given in the response charts (ductility ratio X_m/X_E greater than 100), the response of the element may be obtained through use of the semigraphical method of analysis as outlined in this paragraph considering the simplified pressure pulse. It should be noted that the resistance time relationship used in the analysis to express the element's response should include the elasto-plastic region.

3-20.2 Determination of Time to Reach Maximum Deflection.

The time t_m for each of the cases covered previously can be determined by applying Equations 3-87 and 3-88 to the particular problem. The resulting equations are as follows:

Case 1 - large deflections.

A. $X_1 < X_m \leq X_u$

$$t_m = \frac{i_b}{r_u} + \left[\frac{m_{up}}{m_u r_{up}} - \frac{1}{r_u}\right]\left[i_b^{\,2} - 2m_u r_u X_1\right]^{1/2} \qquad 3\text{-}95$$

B. $X_m \leq X_1$

$$t_m = i_b / r_u \qquad 3\text{-}96$$

Case 2 - limited deflections.

Since the variation of resistance with time is not known in the elasto-plastic range, t_m can only be determined approximately by assuming a linear variation of resistance with time.

$$t_m(approx) = \frac{i_b}{r_u}\left[3 - \frac{m_u}{2m_a}\right] + \frac{1}{r_u}\left[\frac{m_u}{2m_a} - 1\right]\left[9i_b^{\,2} - 6m_a r_u X_E\right]^{1/2} \qquad 3\text{-}97$$

Figure 3-45 Acceleration Impulse Extrapolation Method

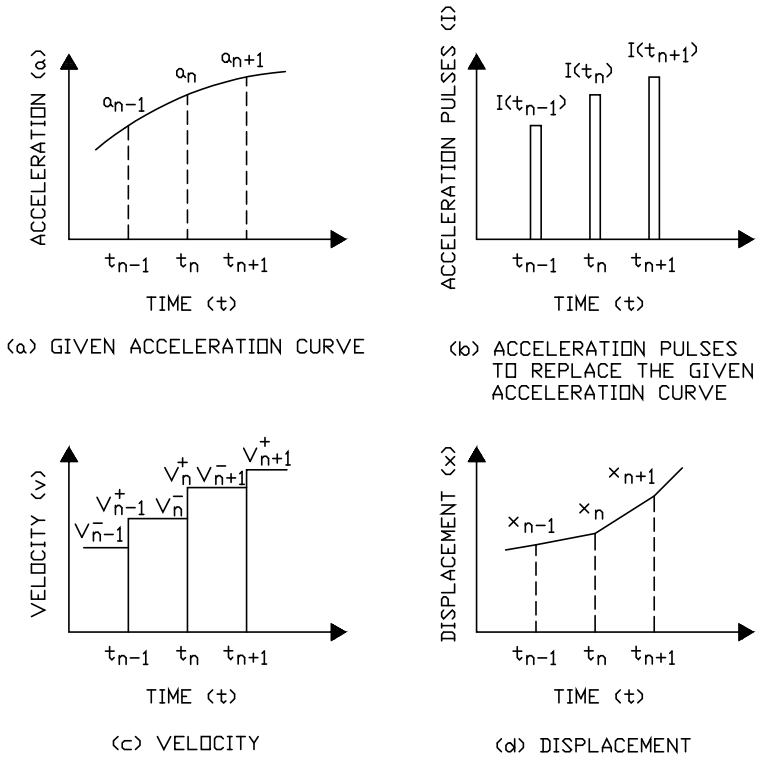


Figure 3-46 Discontinuities in the Acceleration Curve

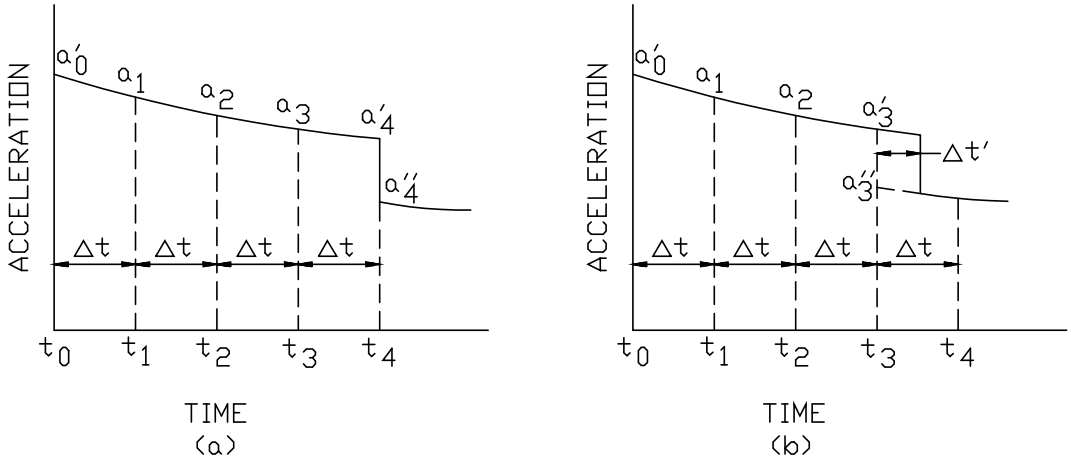


Figure 3-47 Pressure-Time Function with Two Different Time Intervals

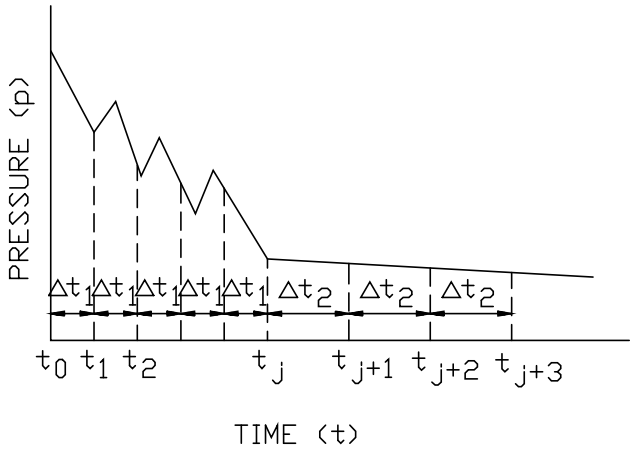


Figure 3-48 A Two-Degrees-of-Freedom System

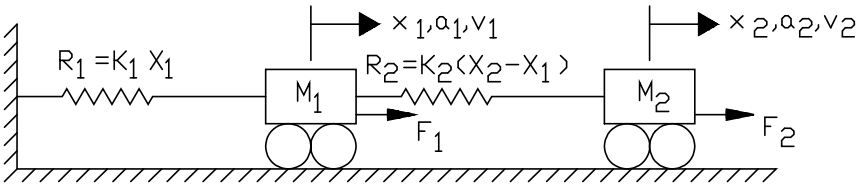


Figure 3-49 Maximum Response of Elastic, One-Degree-of-Freedom System for Triangular Load

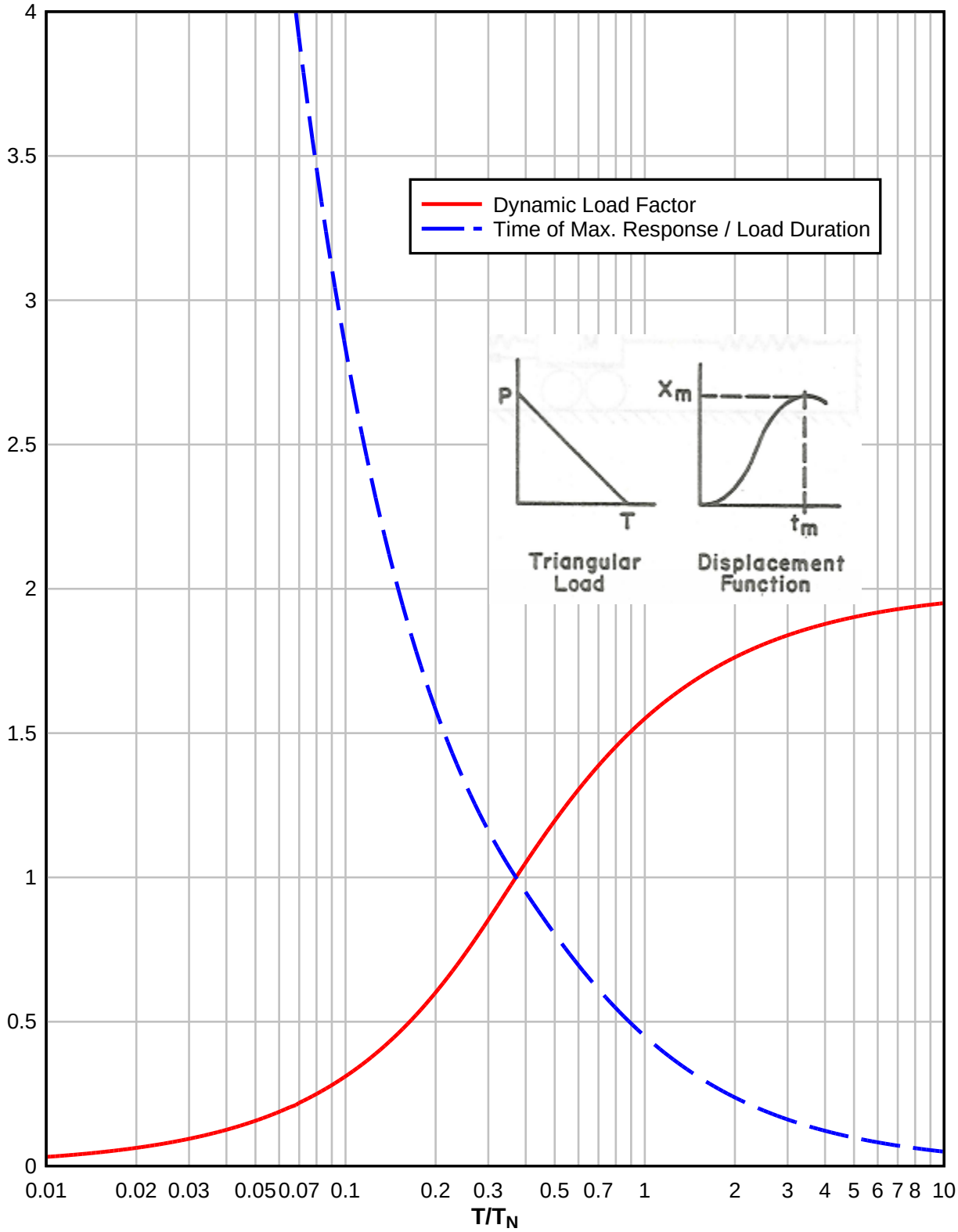


Figure 3-50 Maximum Response of Elastic, One-Degree-of-Freedom System for Rectangular Load

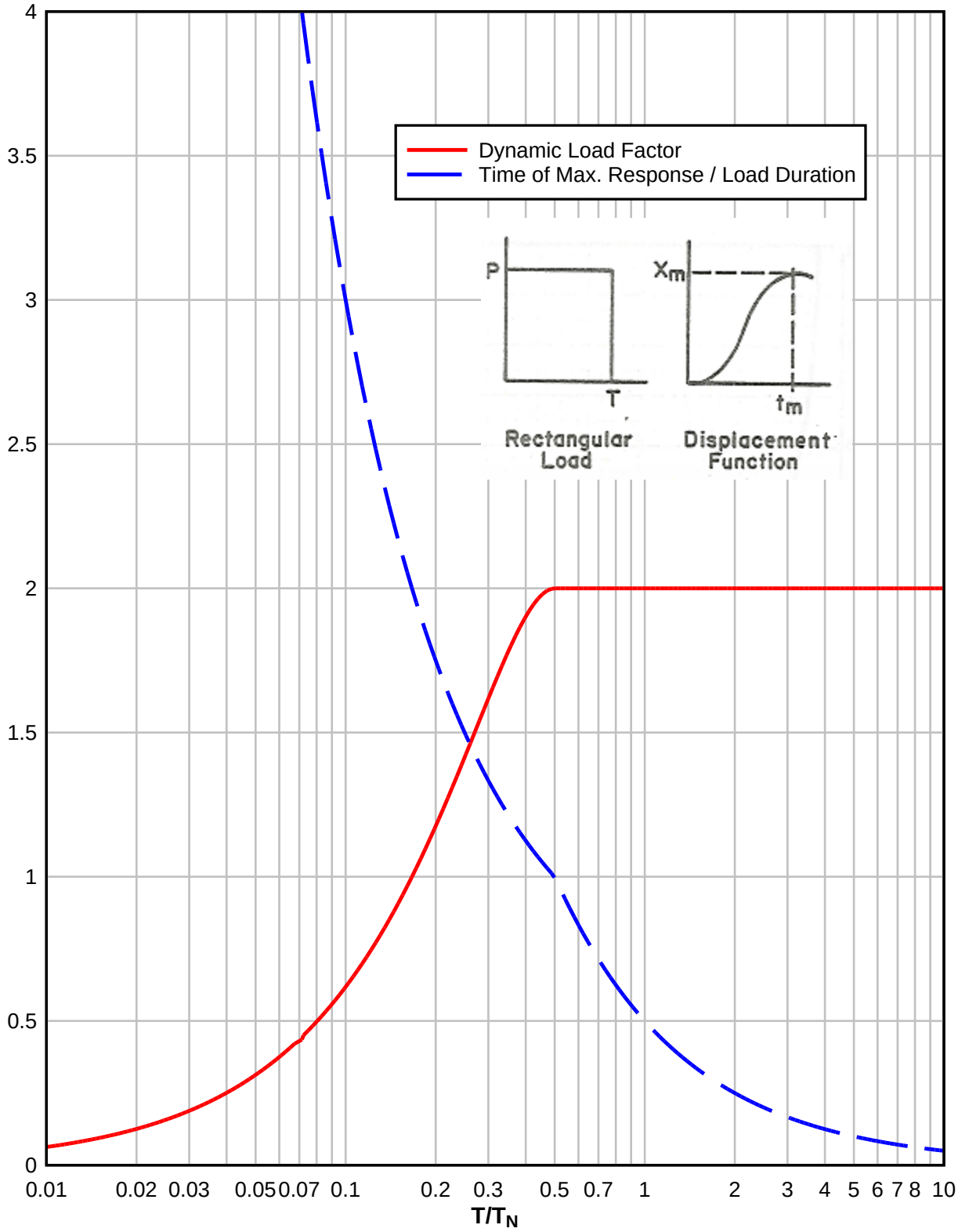


Figure 3-51 Maximum Response of Elastic, One-Degree-of-Freedom System for Gradually Applied Load

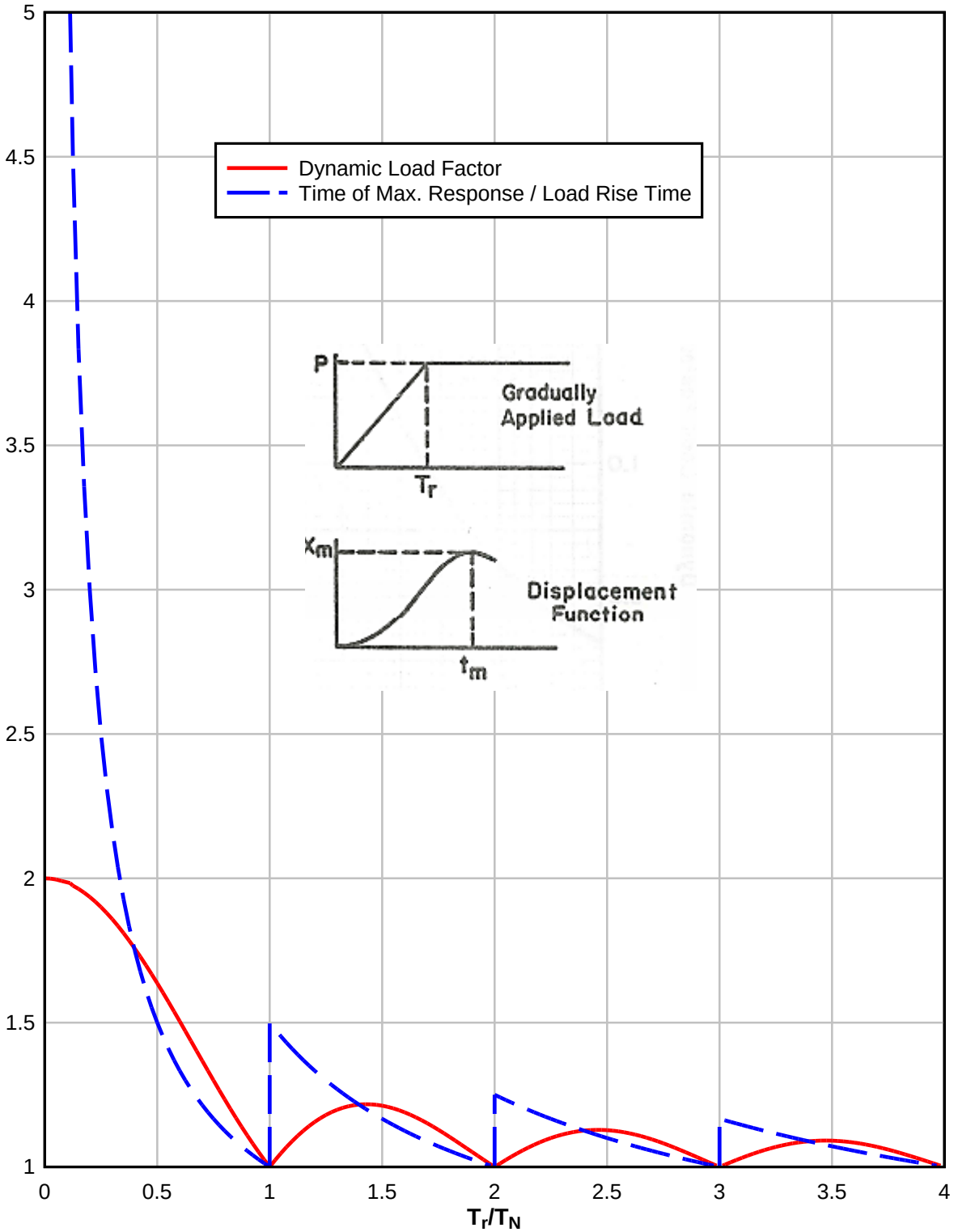


Figure 3-52 Maximum Response of Elastic, One-Degree-of-Freedom System for Triangular Pulse Load

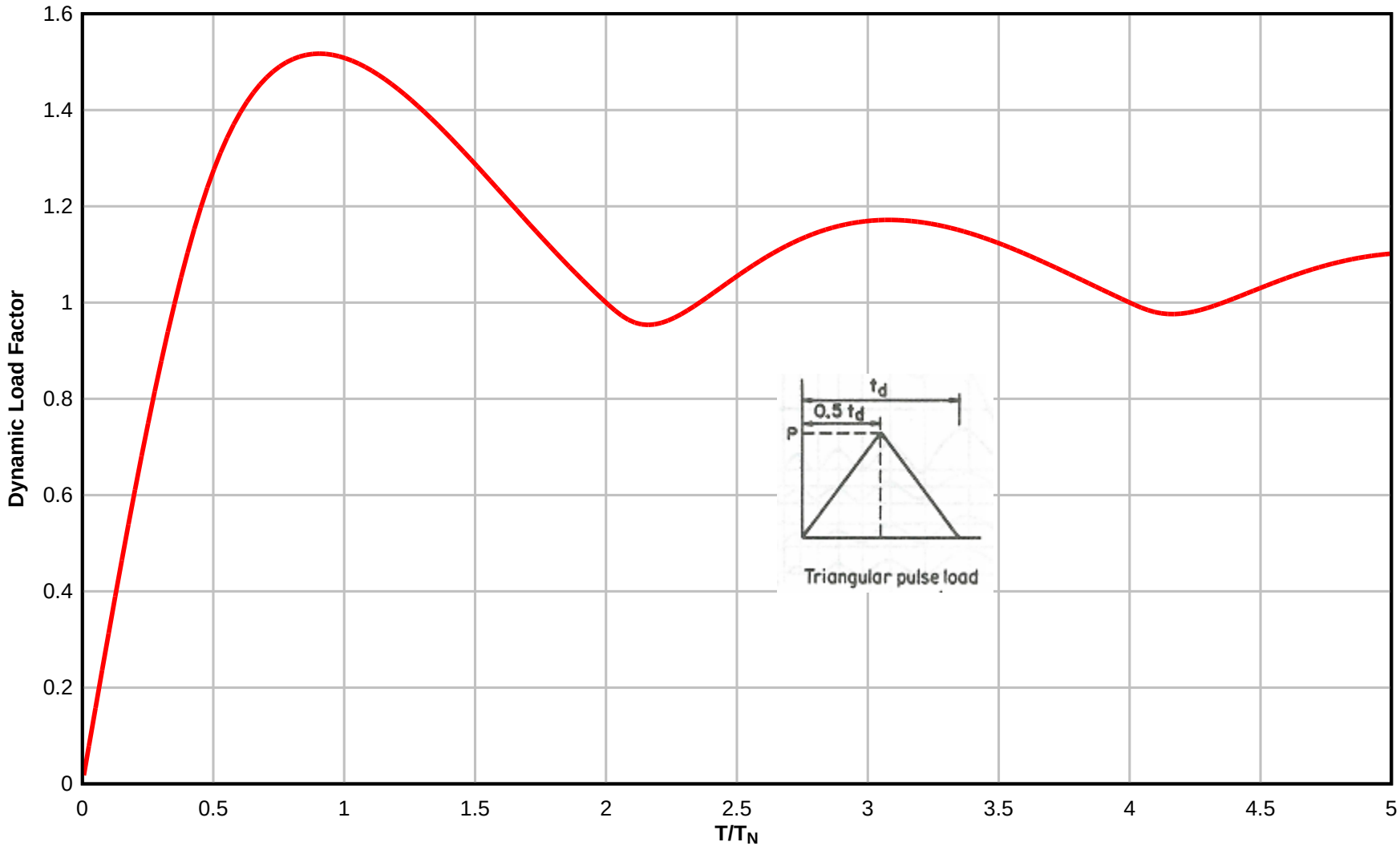


Figure 3-53 Maximum Response of Elastic, One-Degree-of-Freedom System for Sinusoidal Pulse Loads

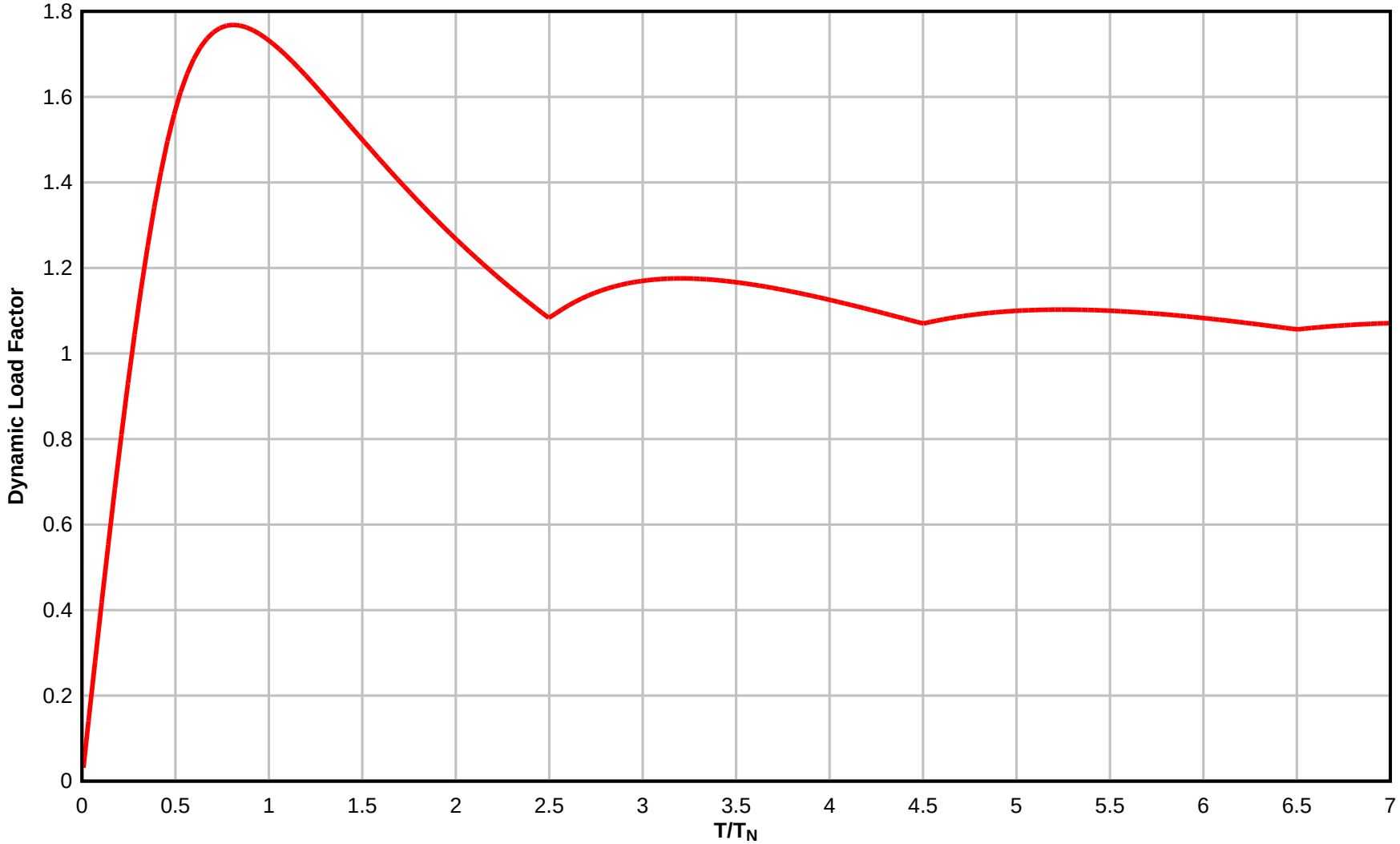


Figure 3-54 Maximum Deflection of Elasto-Plastic, One-Degree-of-Freedom System for Triangular Load

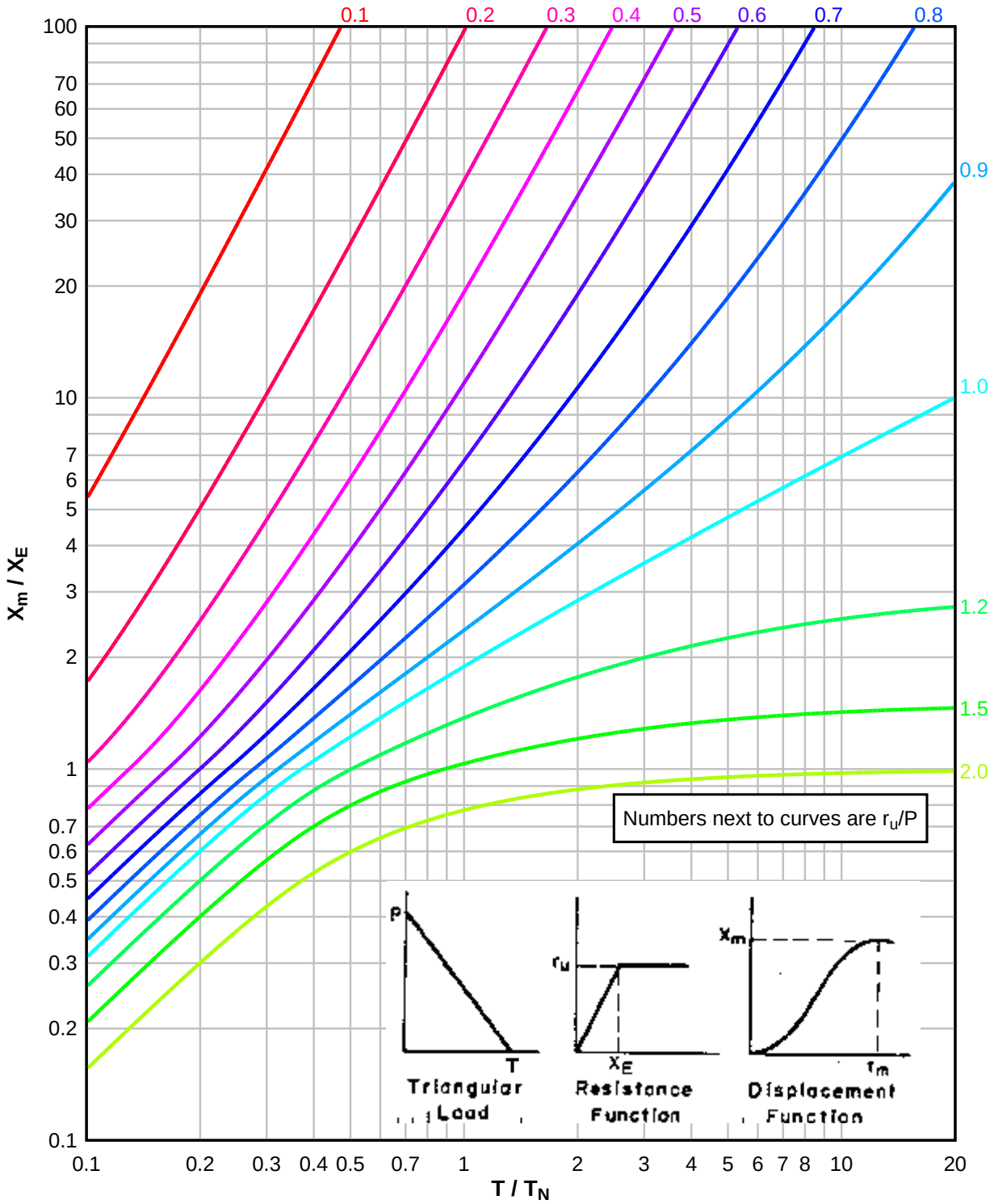


Figure 3-55 Maximum Response Time of Elasto-Plastic, One-Degree-of-Freedom System for Triangular Load

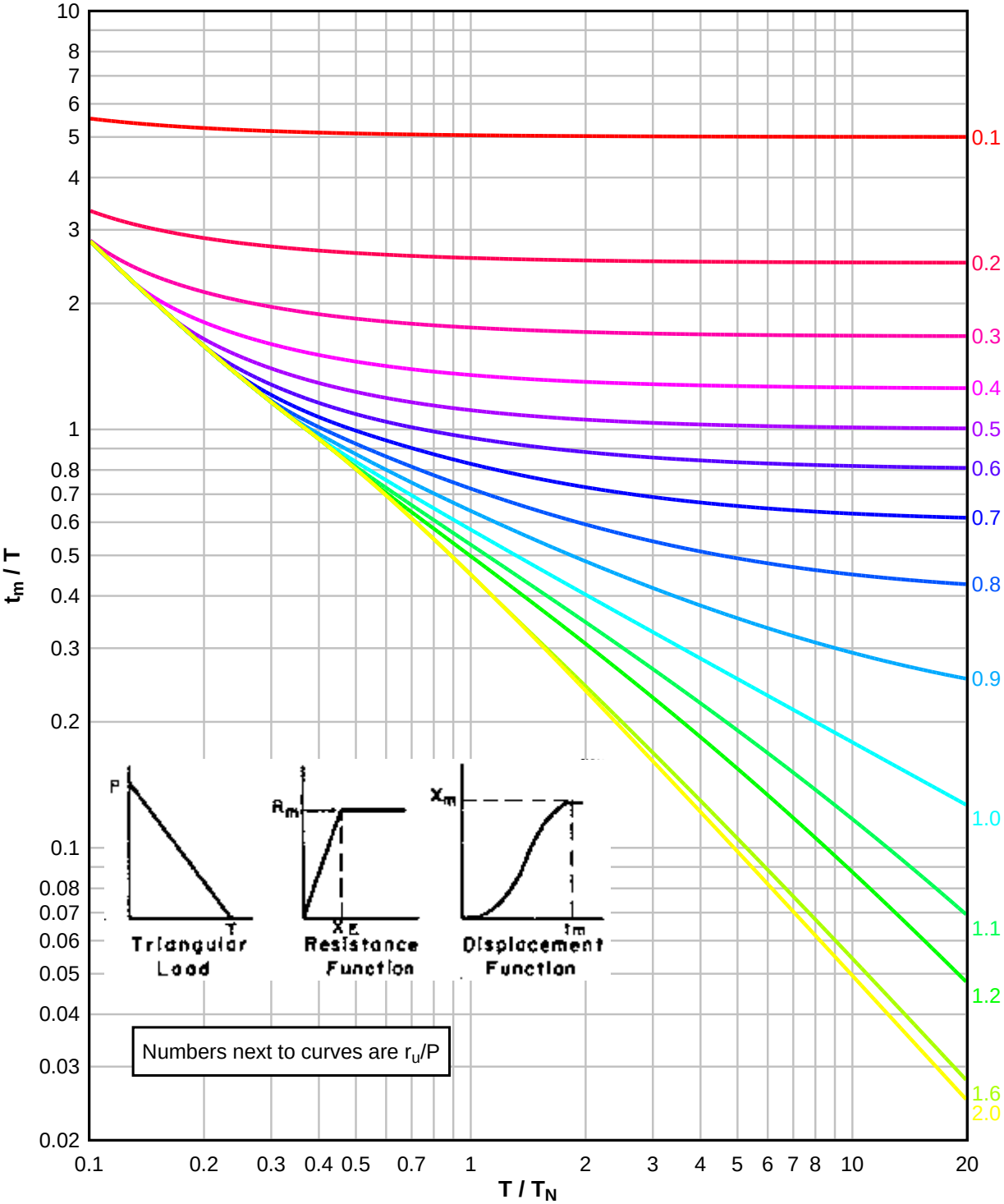


Figure 3-56 Maximum Deflection of Elasto-Plastic, One-Degree-of-Freedom System for Rectangular Load

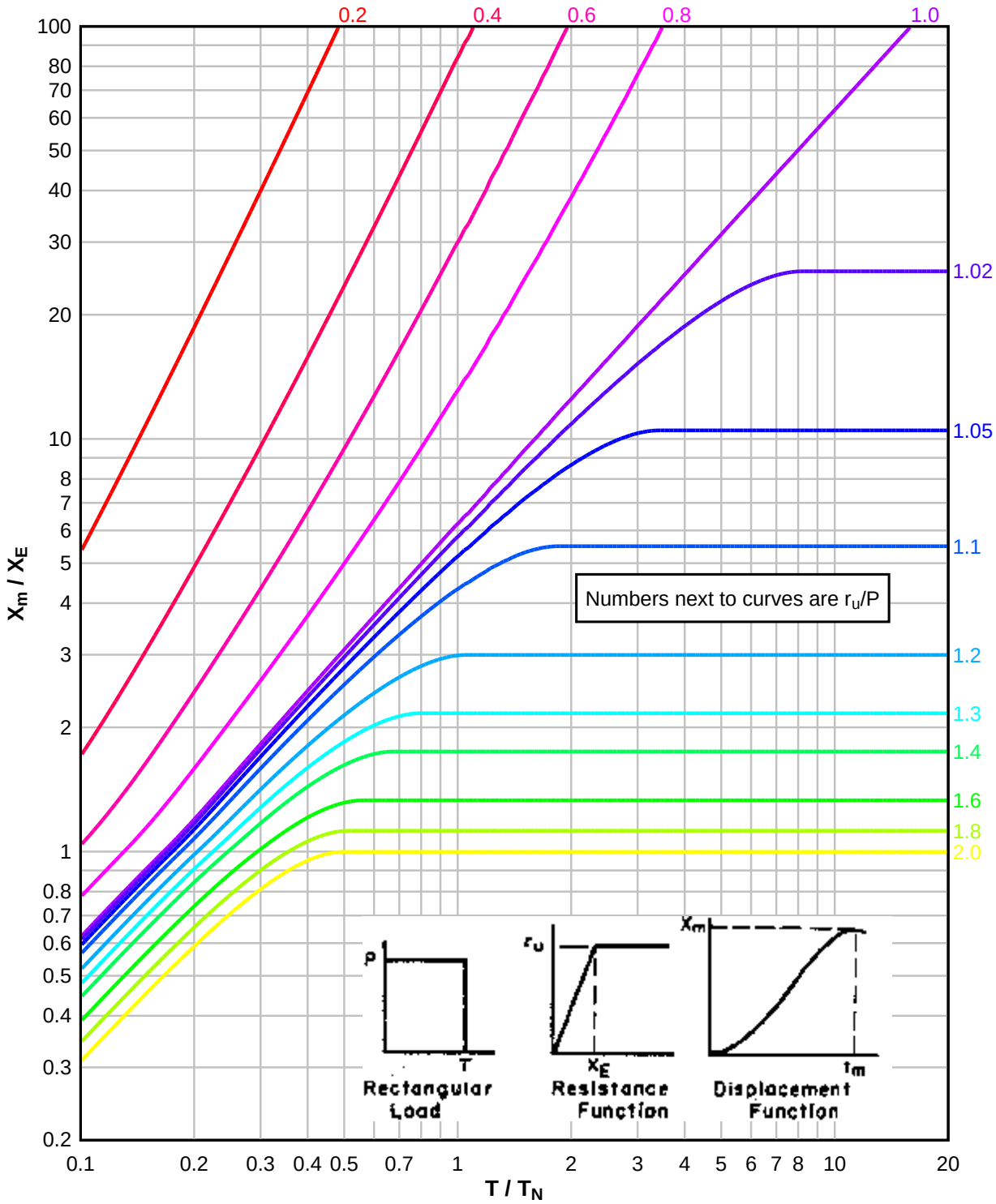


Figure 3-57 Maximum Response Time of Elasto-Plastic, One-Degree-of-Freedom System for Rectangular Load

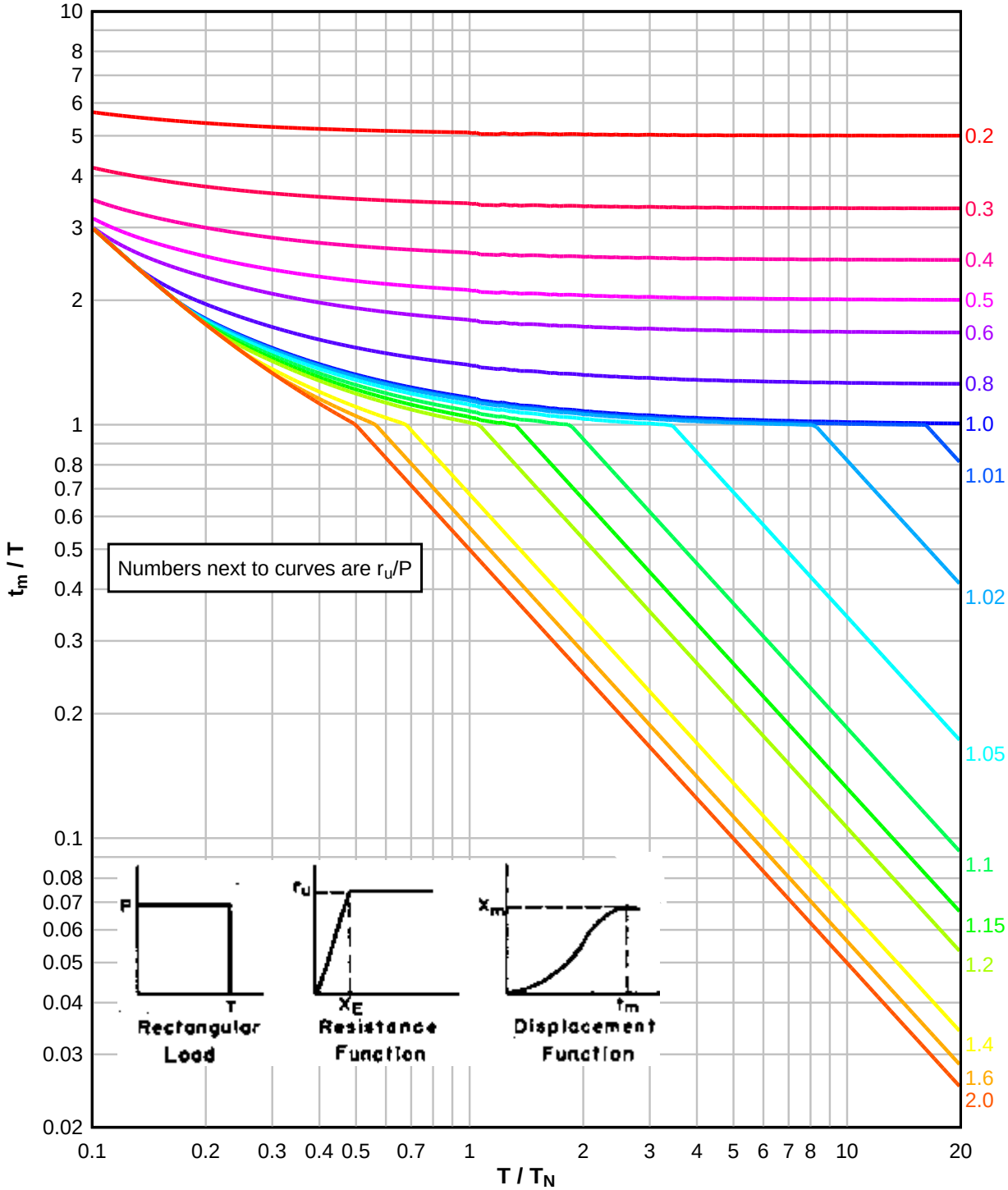


Figure 3-58 Maximum Deflection of Elasto-Plastic, One-Degree-of-Freedom System for Gradually Applied Load

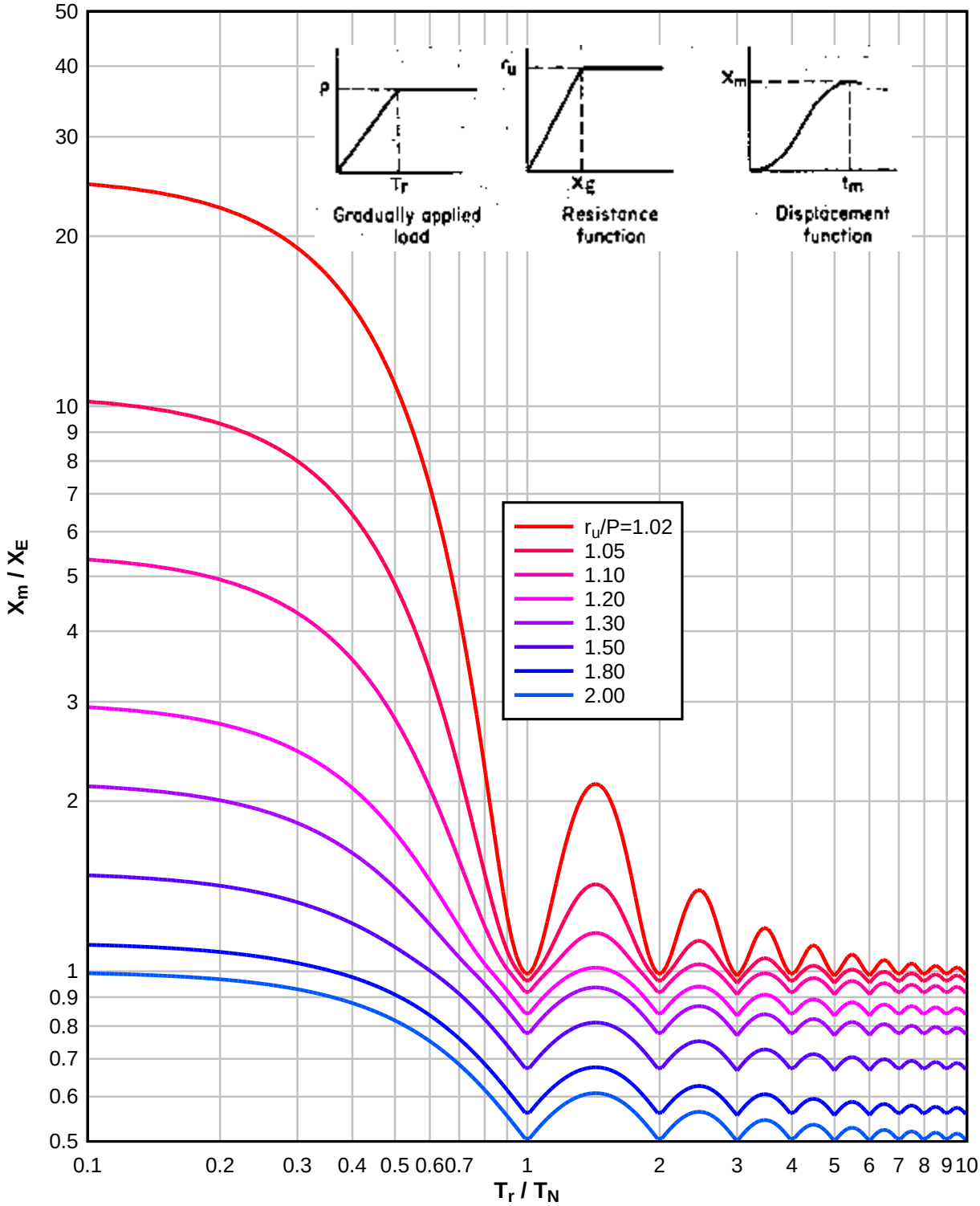


Figure 3-59 Maximum Response Time of Elasto-Plastic, One-Degree-of-Freedom System for Gradually Applied Load

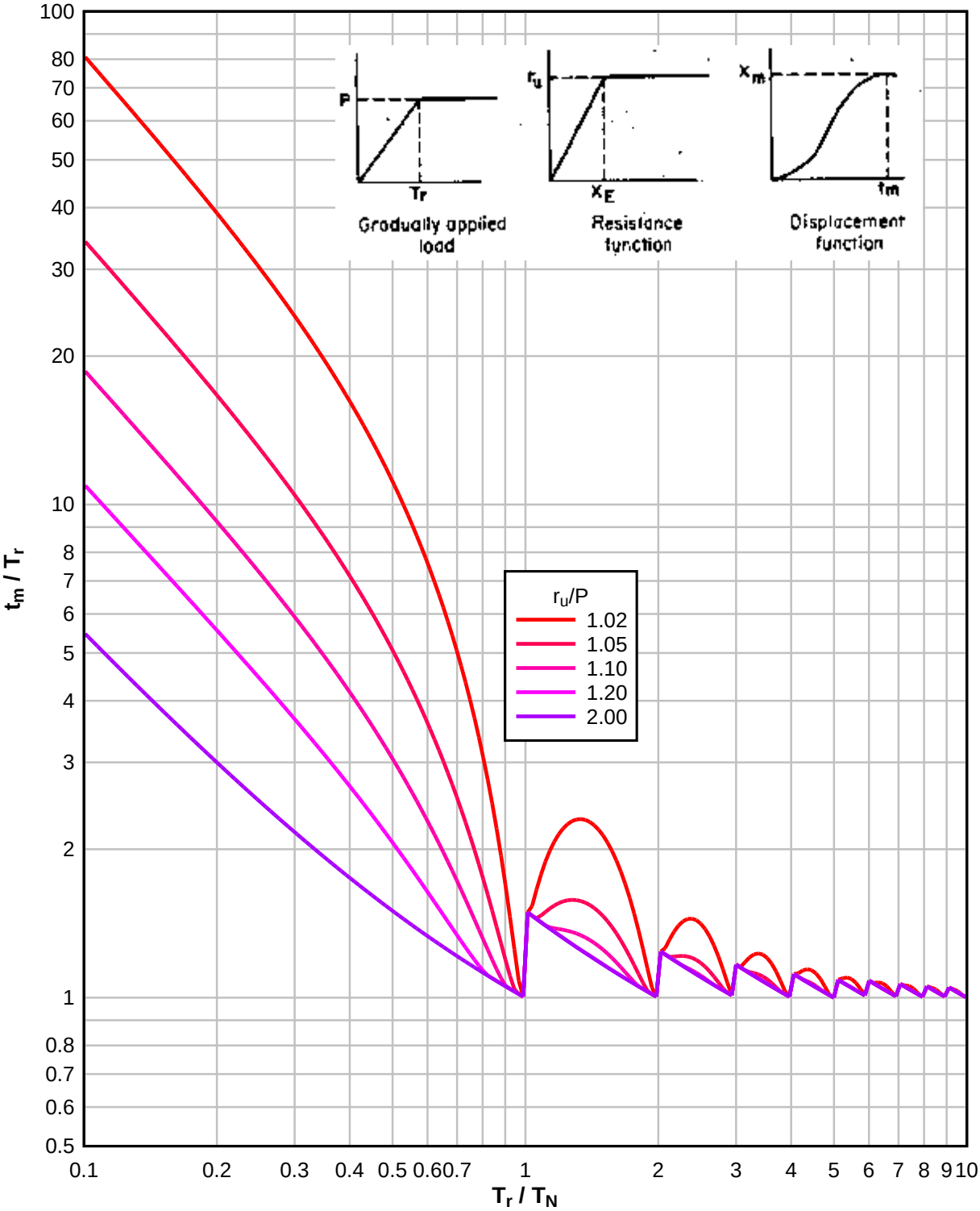


Figure 3-60 Maximum Deflection of Elasto-Plastic, One-Degree-of-Freedom System for Triangular Pulse Load

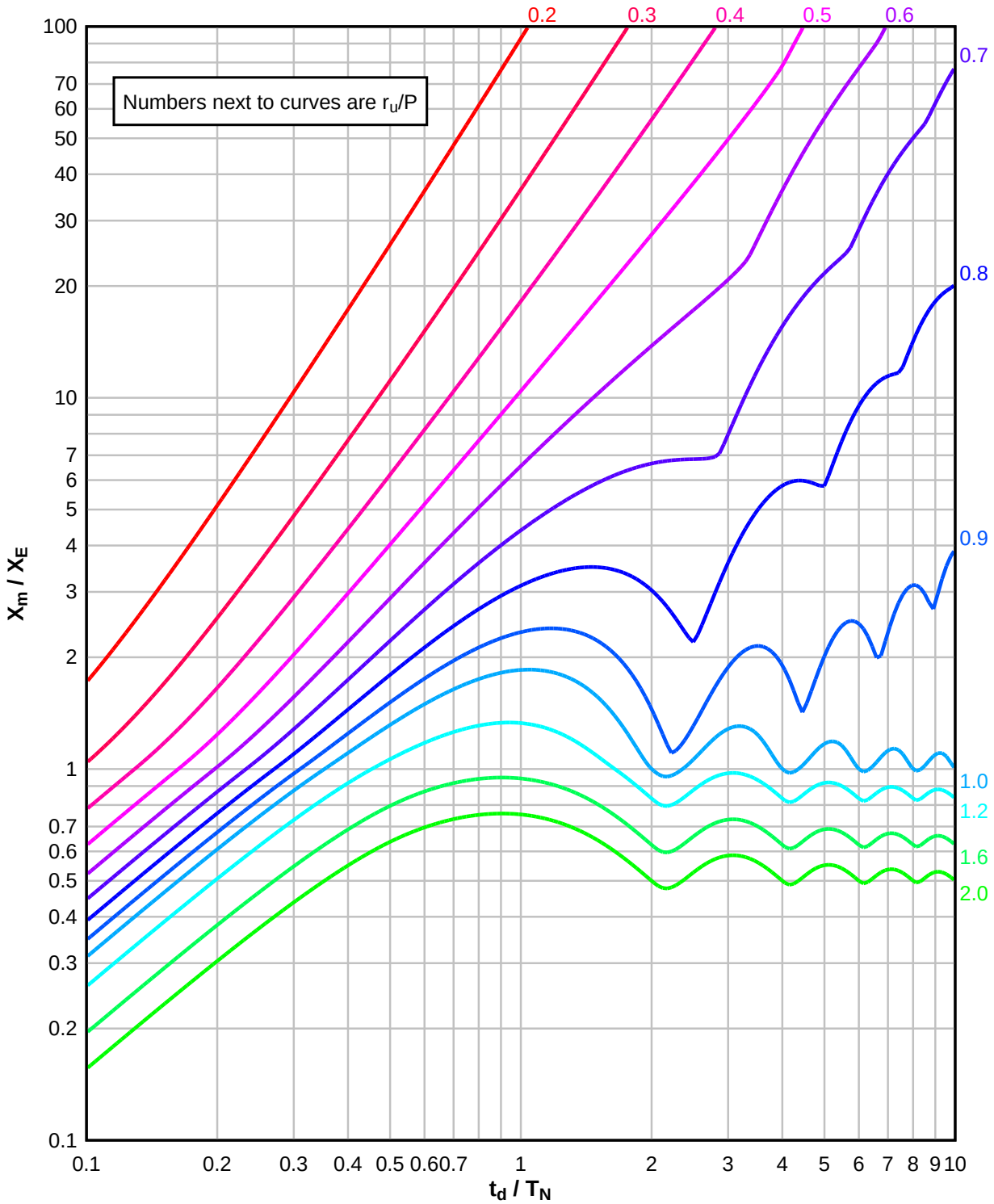


Figure 3-61 Maximum Response Time of Elasto-Plastic, One-Degree-of-Freedom System for Triangular Pulse Load

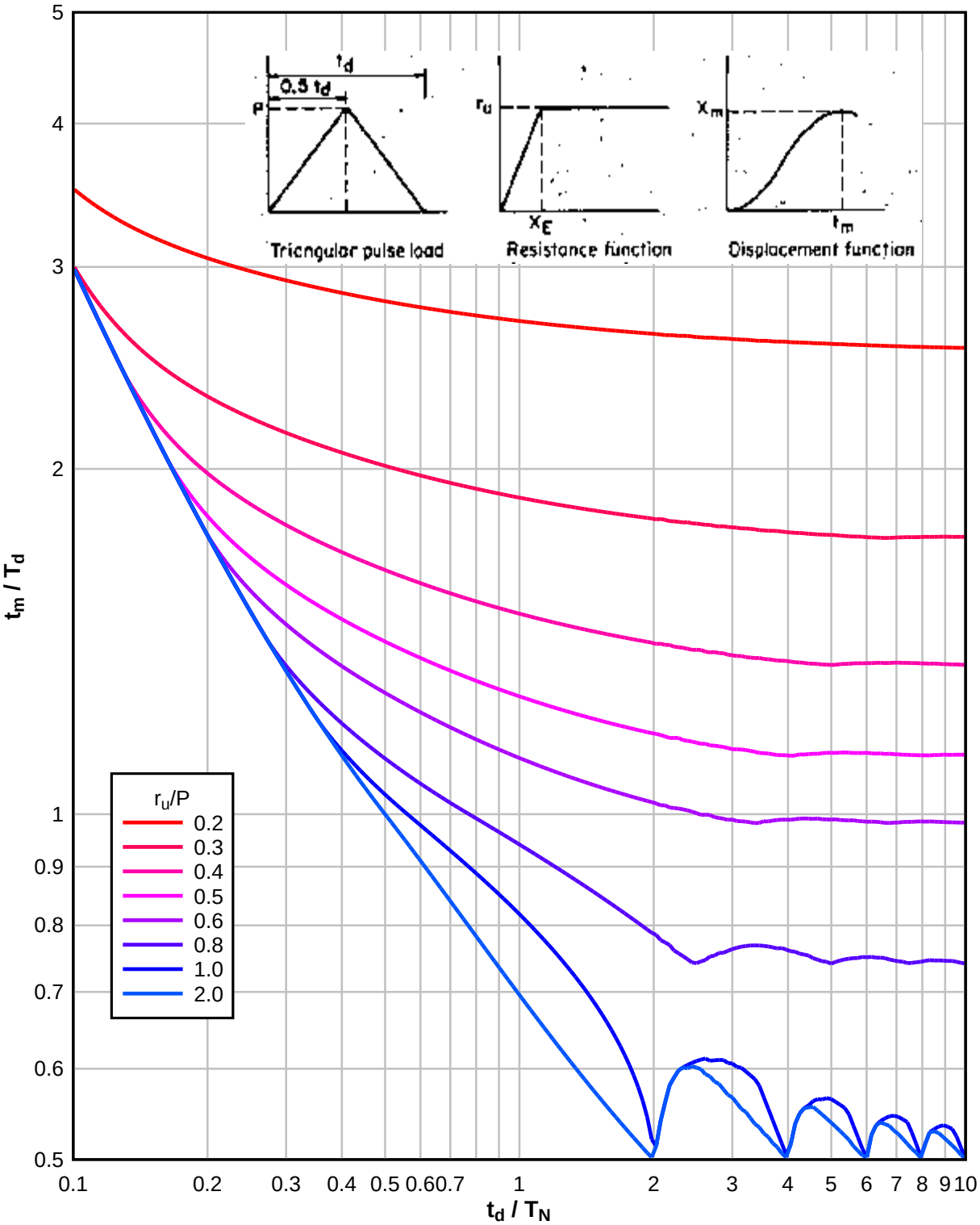


Figure 3-62 Various Bilinear Triangular Loads

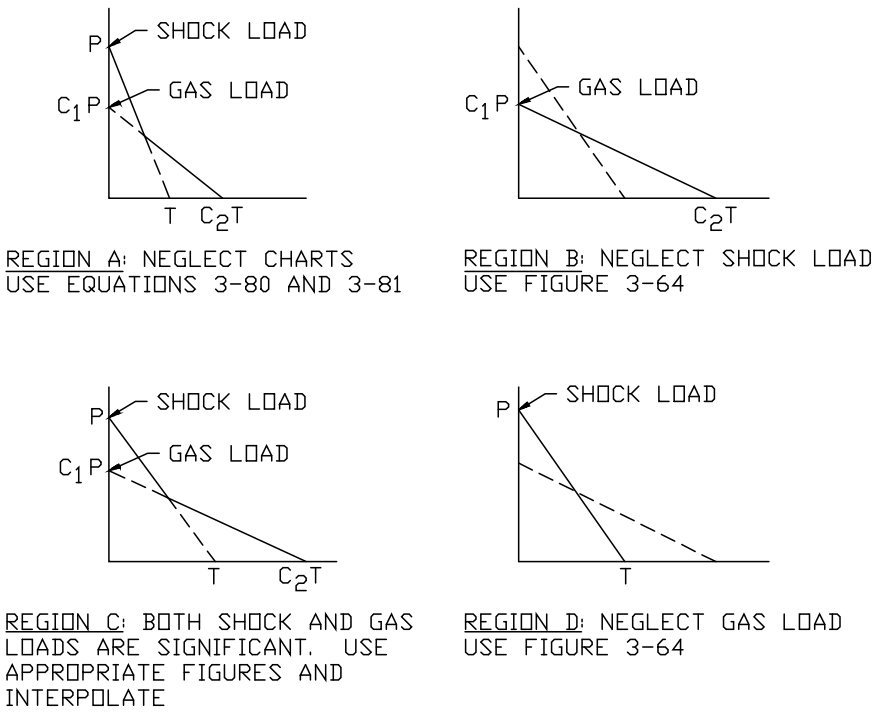


Figure 3-63 Regions of Figures 3-64 Through 3-266, Labeling of Axis and Curves

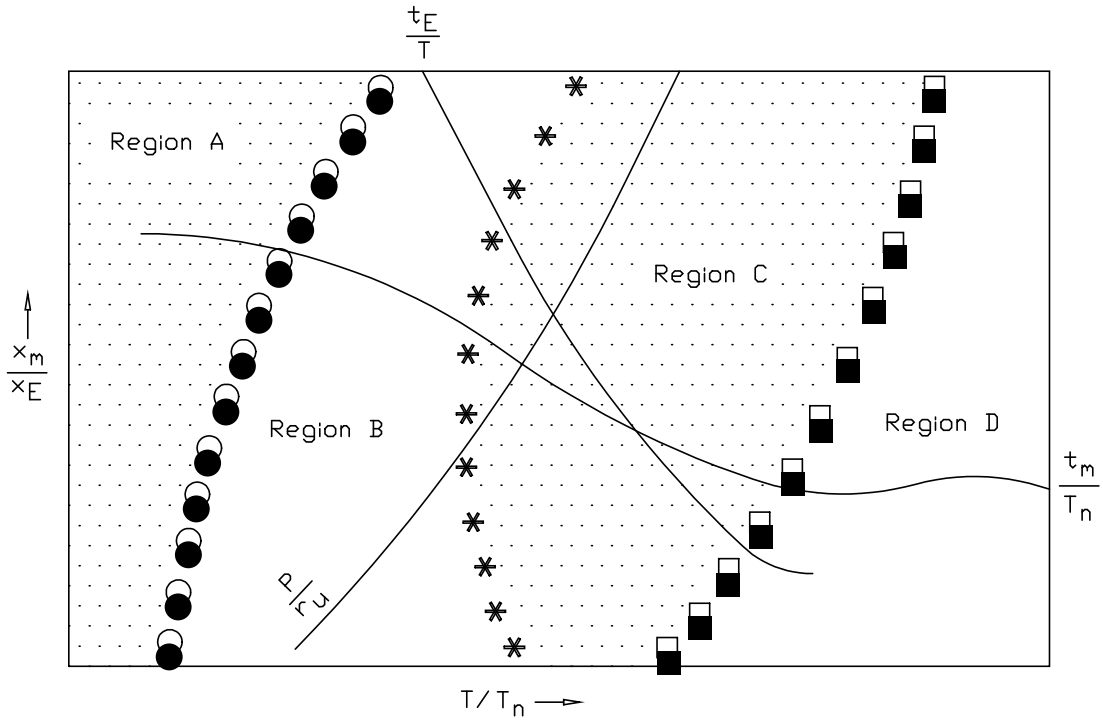


Figure 3-64(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 1.000, C_2 = 1.0)

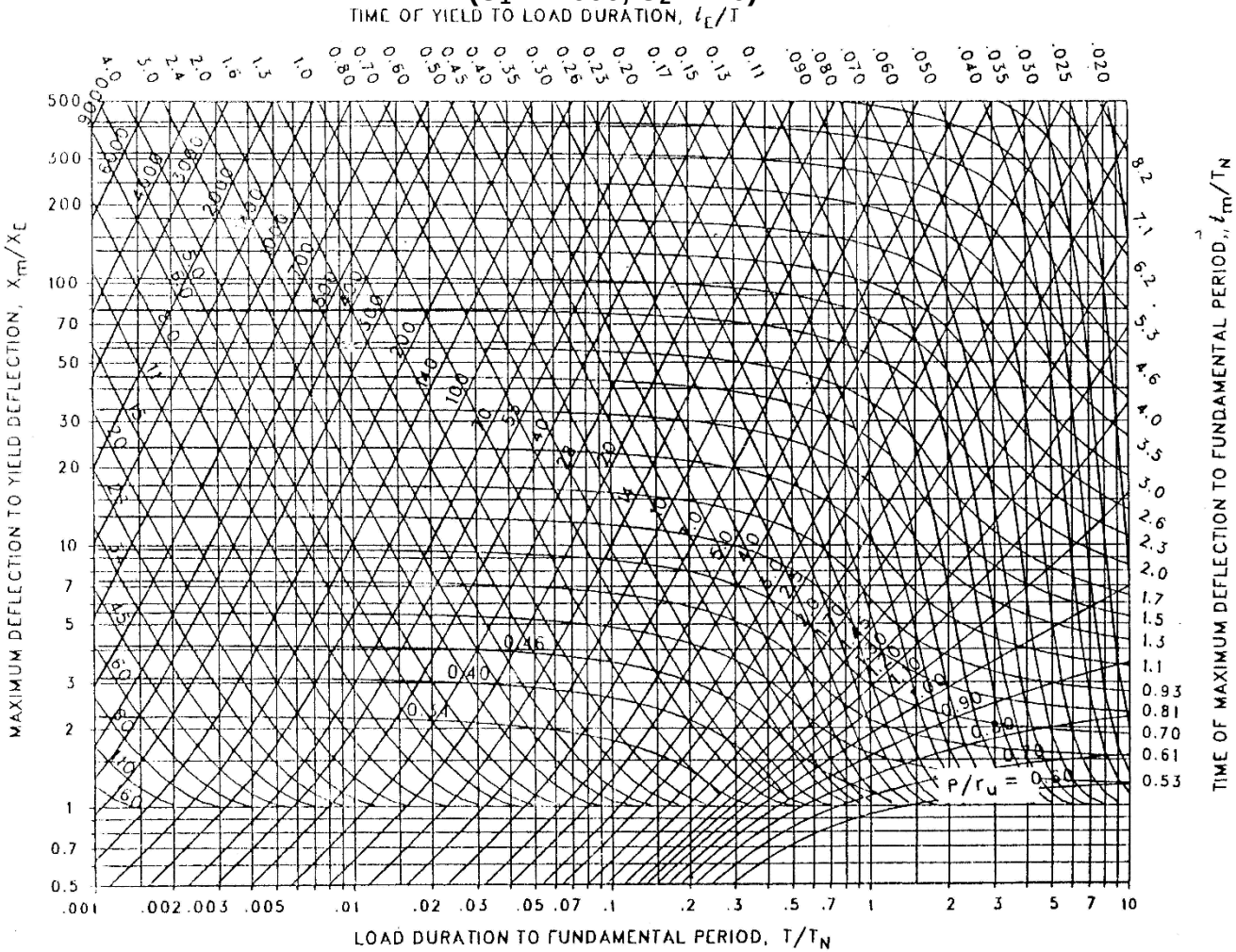


Figure 3-64a Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 1.000, C_2 = 1.0)

Figure 3-64(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 1.000, C2 = 1.0)

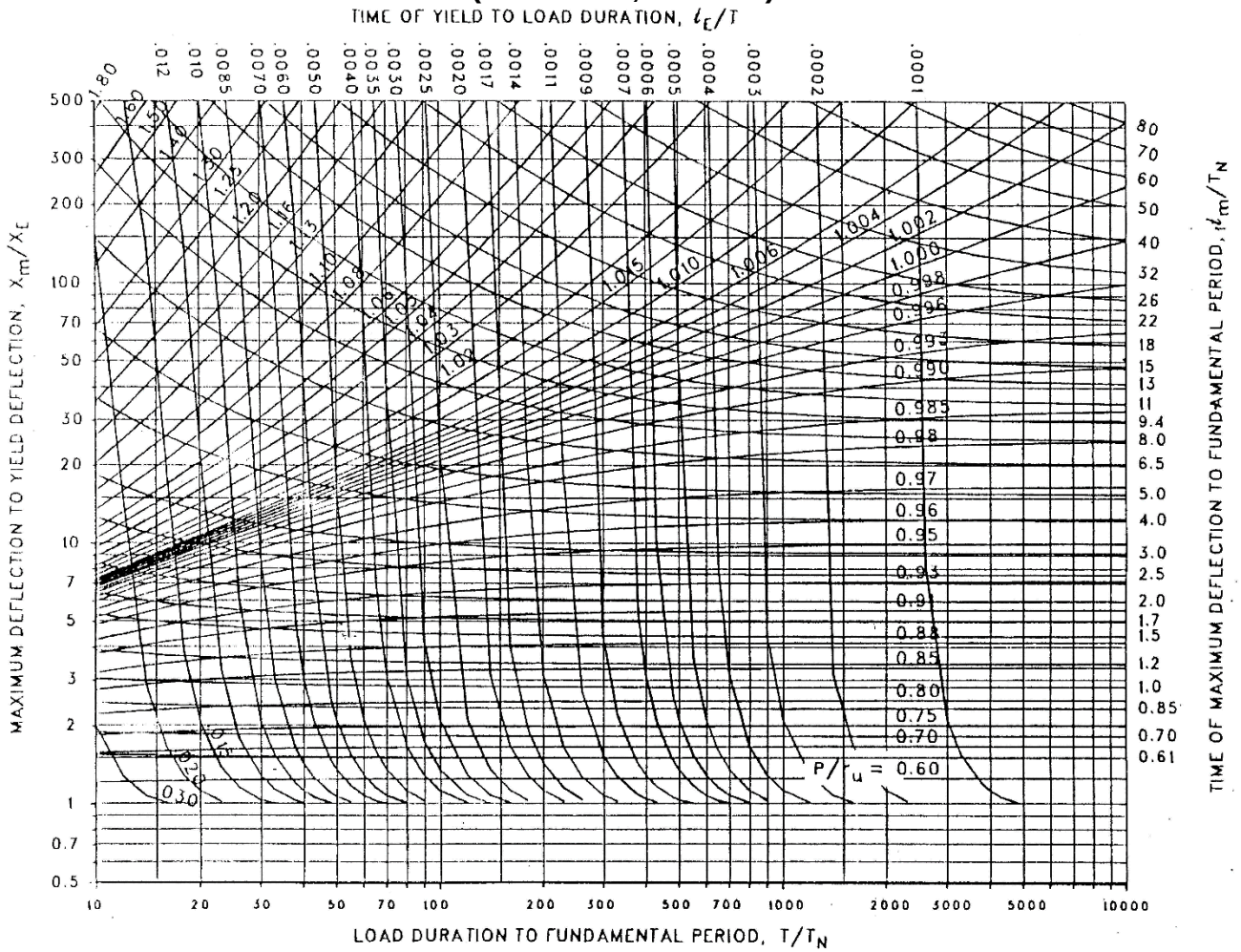


Figure 3-64b Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 1.000, C_2 = 1.0) (cont.)

Figure 3-65(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.681, C_2 = 1.7)

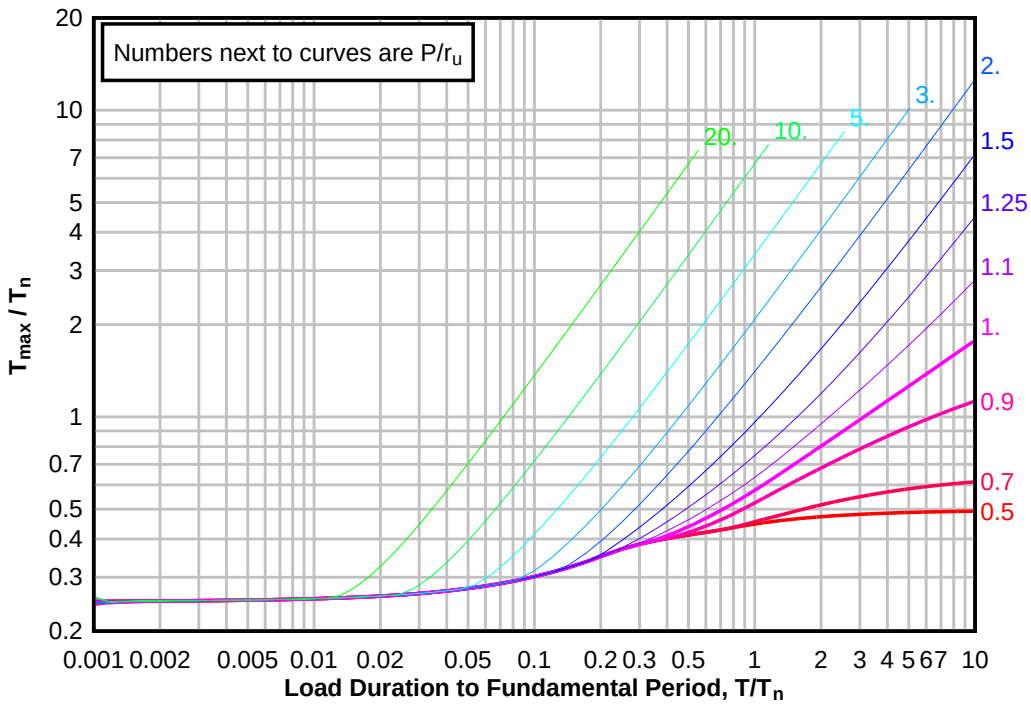


Figure 3-65(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.681, C2 = 1.7)

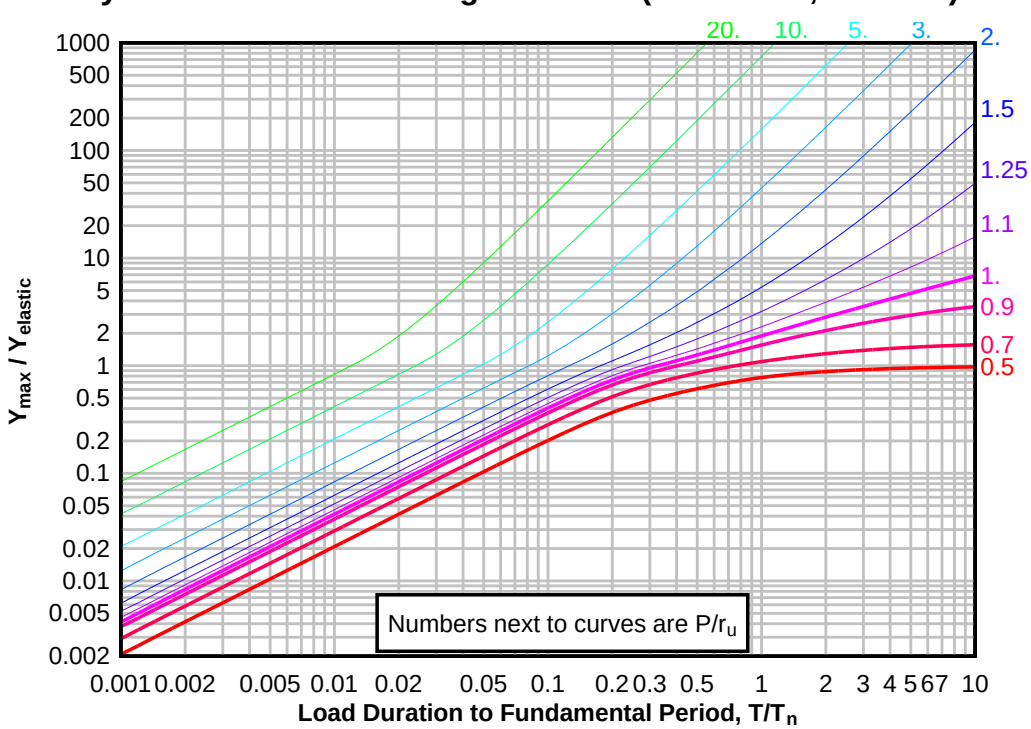


Figure 3-65(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.681, C2 = 1.7)

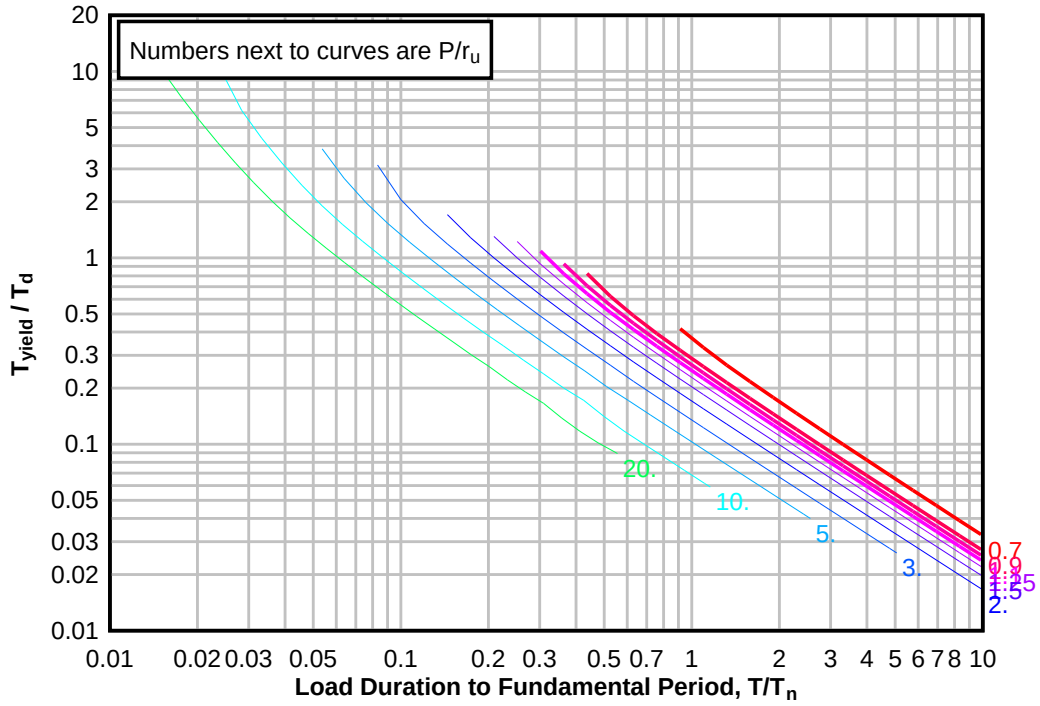


Figure 3-66(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 0.464, C_2 = 1.7)

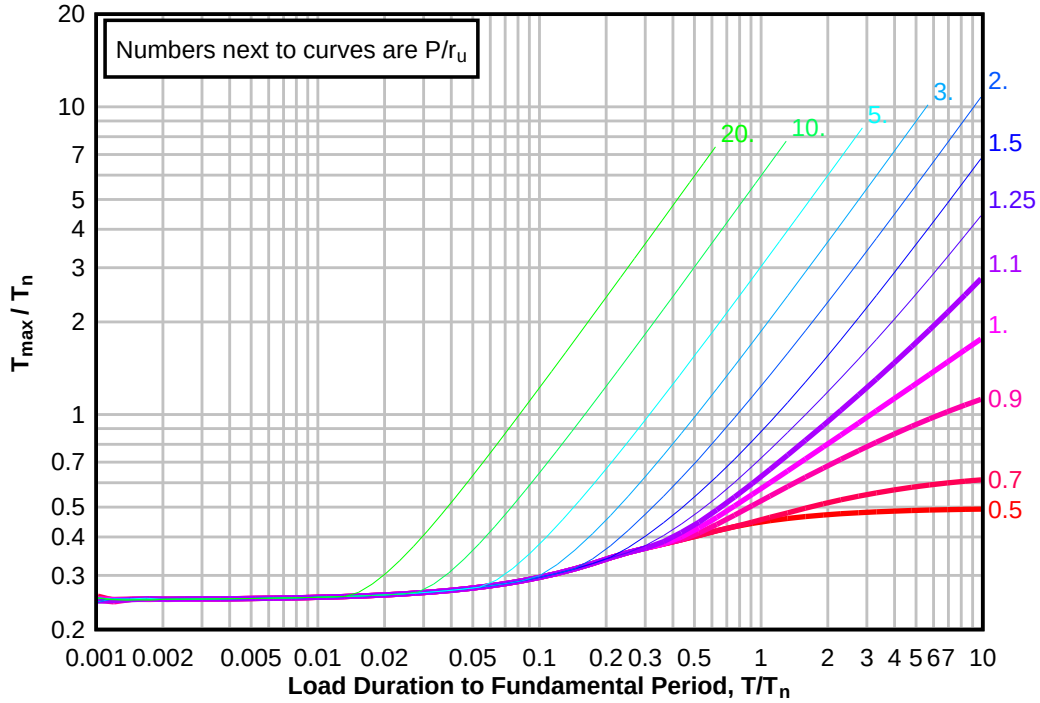


Figure 3-66(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 0.464, C2 = 1.7)

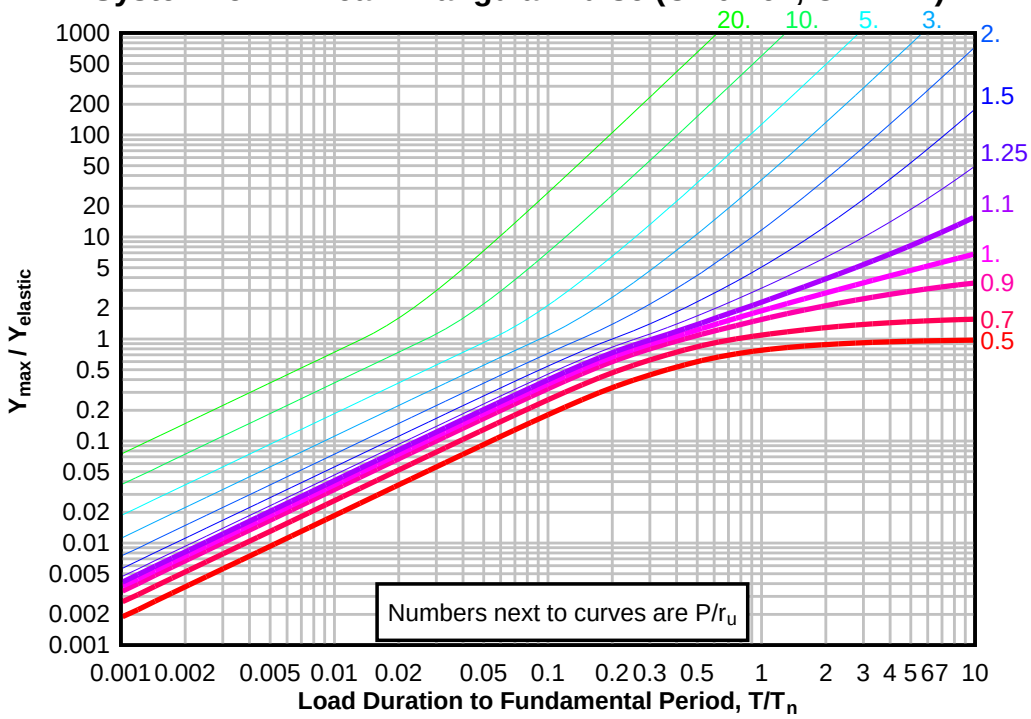


Figure 3-66(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 0.464, C2 = 1.7)

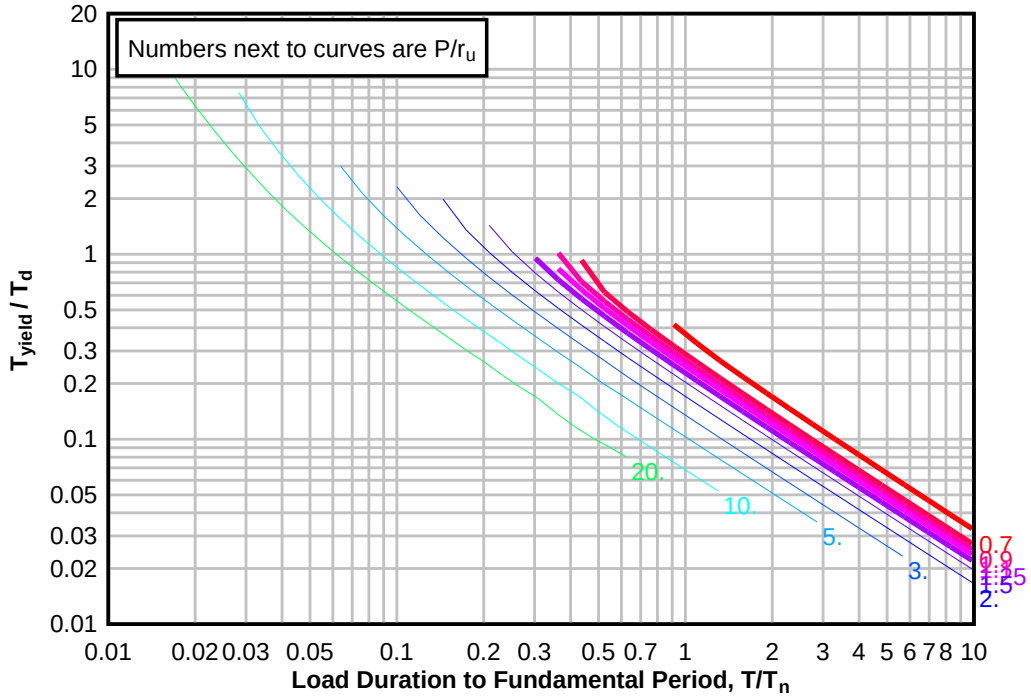


Figure 3-67(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.316, C_2 = 1.7)

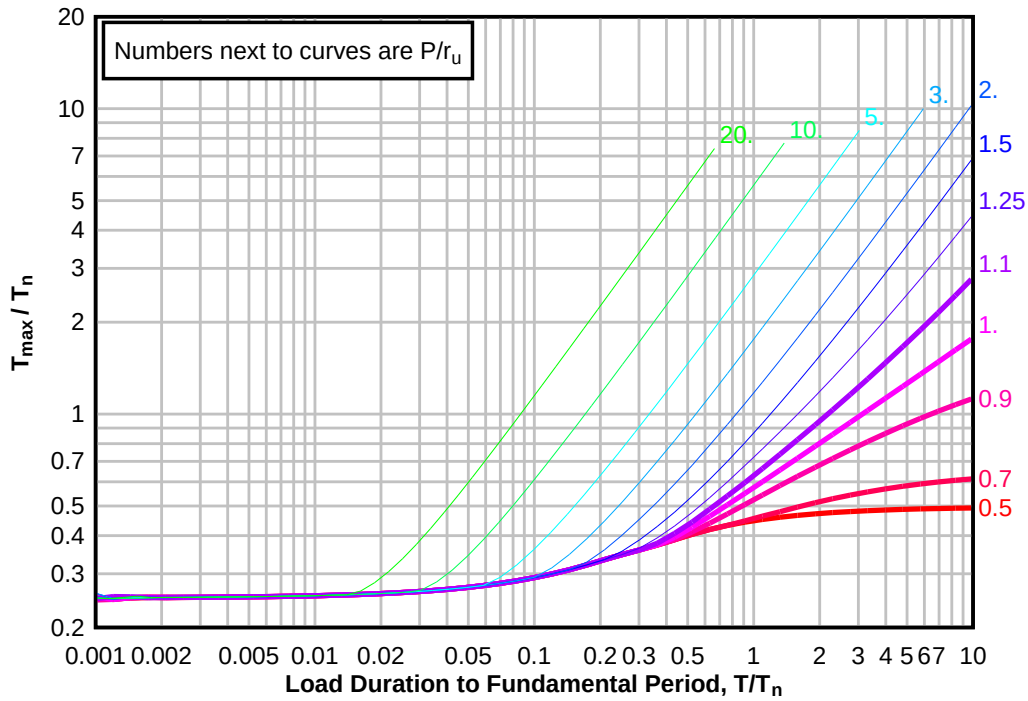


Figure 3-67(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.316, C2 = 1.7)

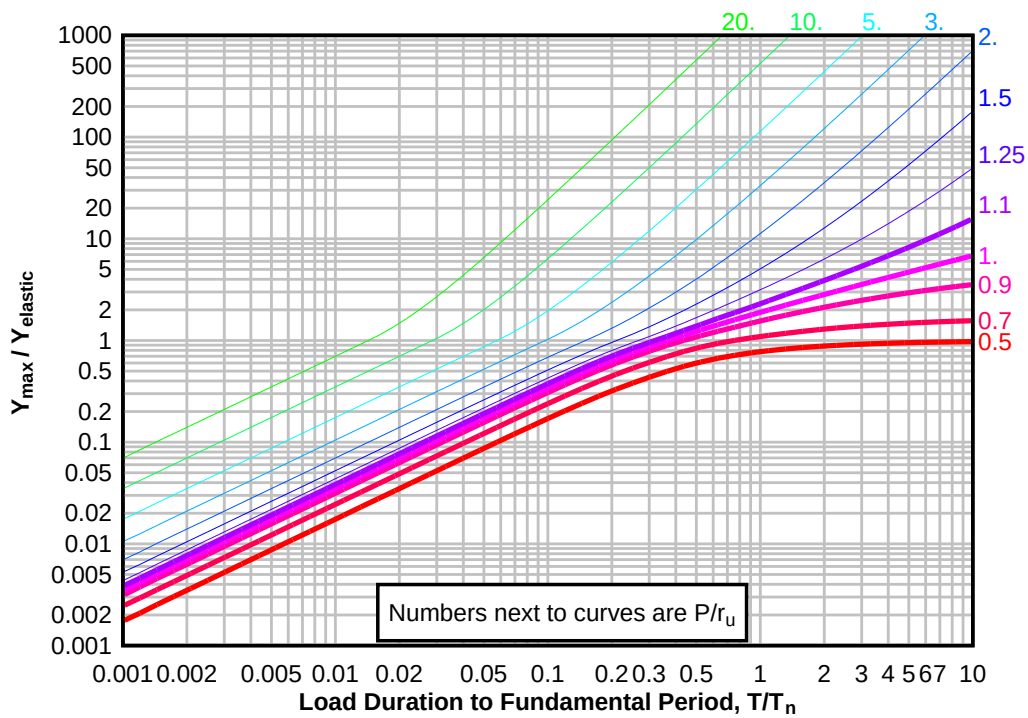


Figure 3-67(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.316, C2 = 1.7)

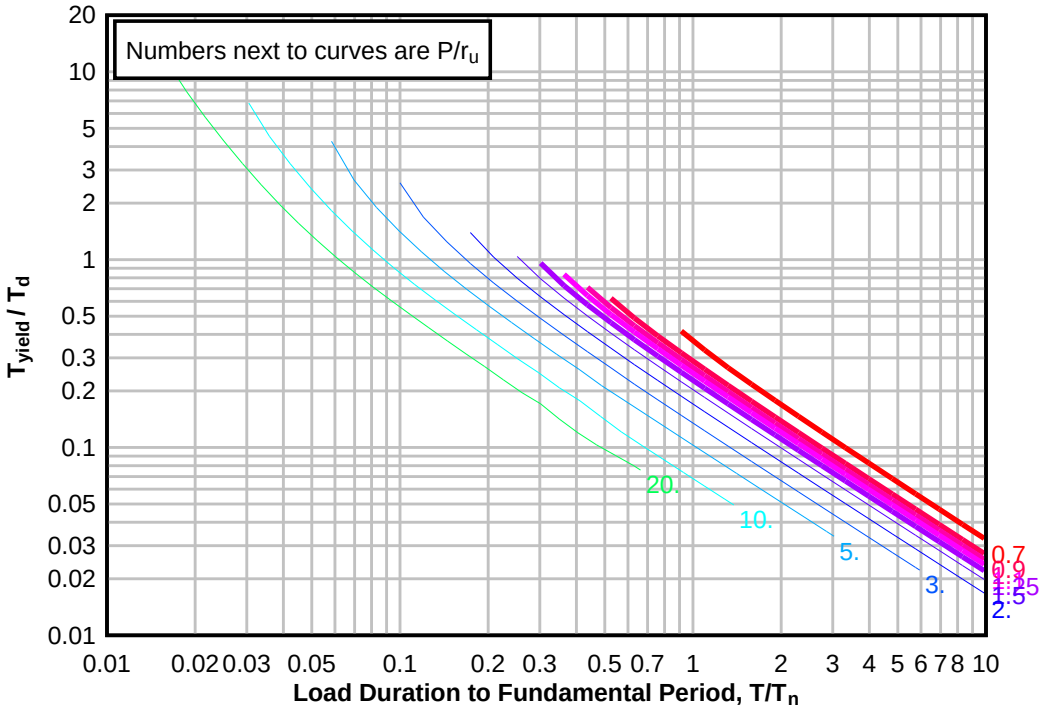


Figure 3-68(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.215, C_2 = 1.7)

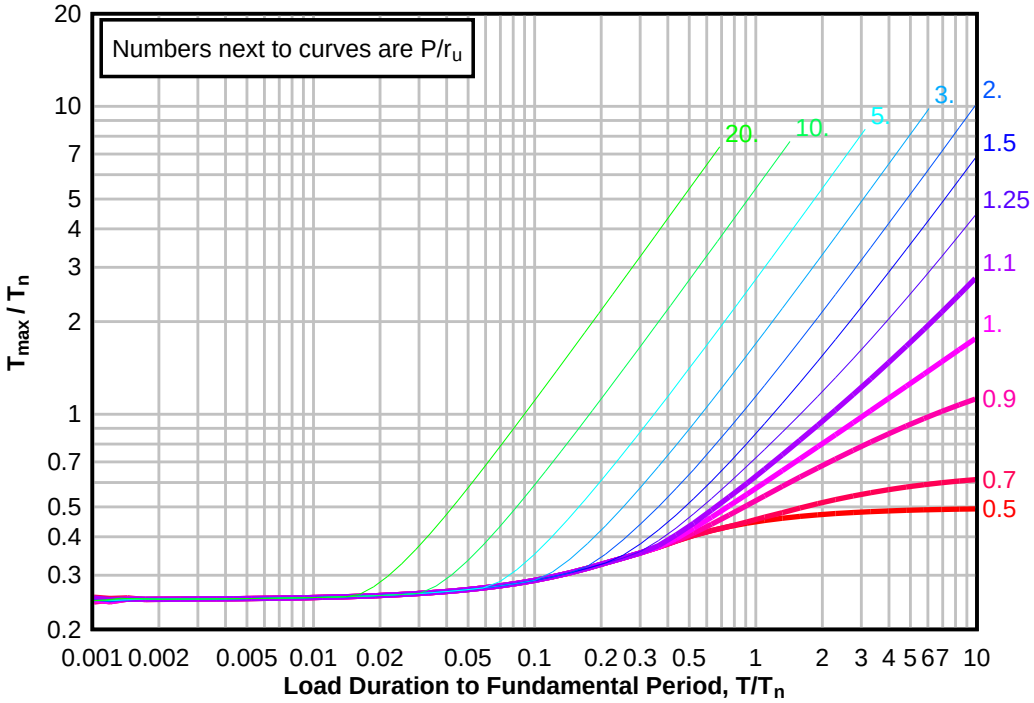


Figure 3 68(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.215, C2 = 1.7)

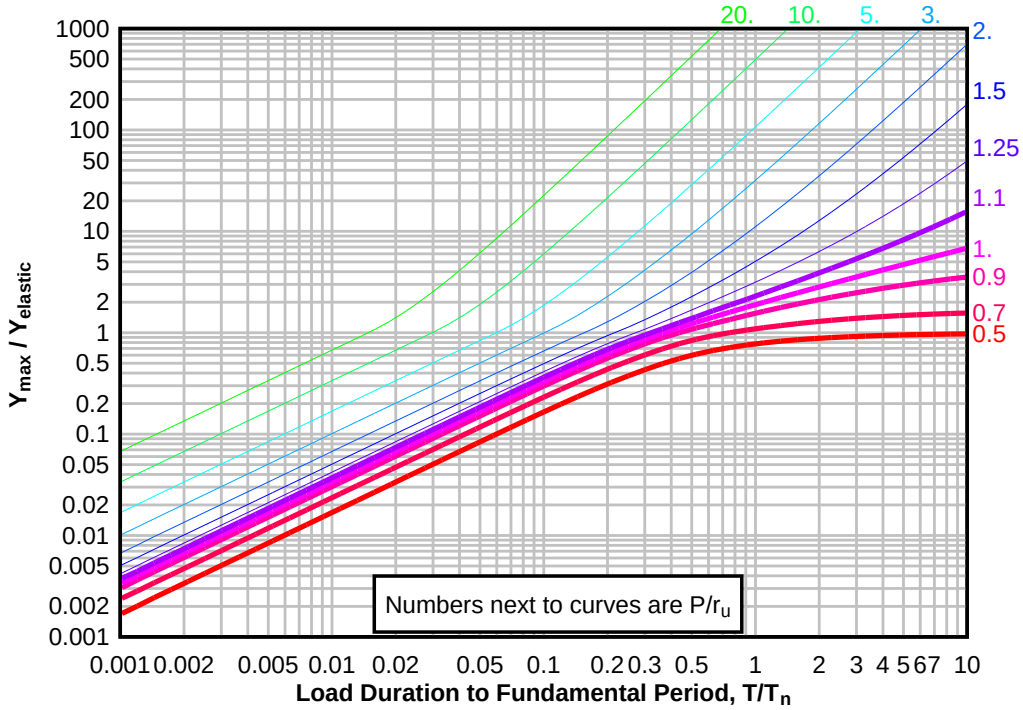


Figure 3-68(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.215, C2 = 1.7)

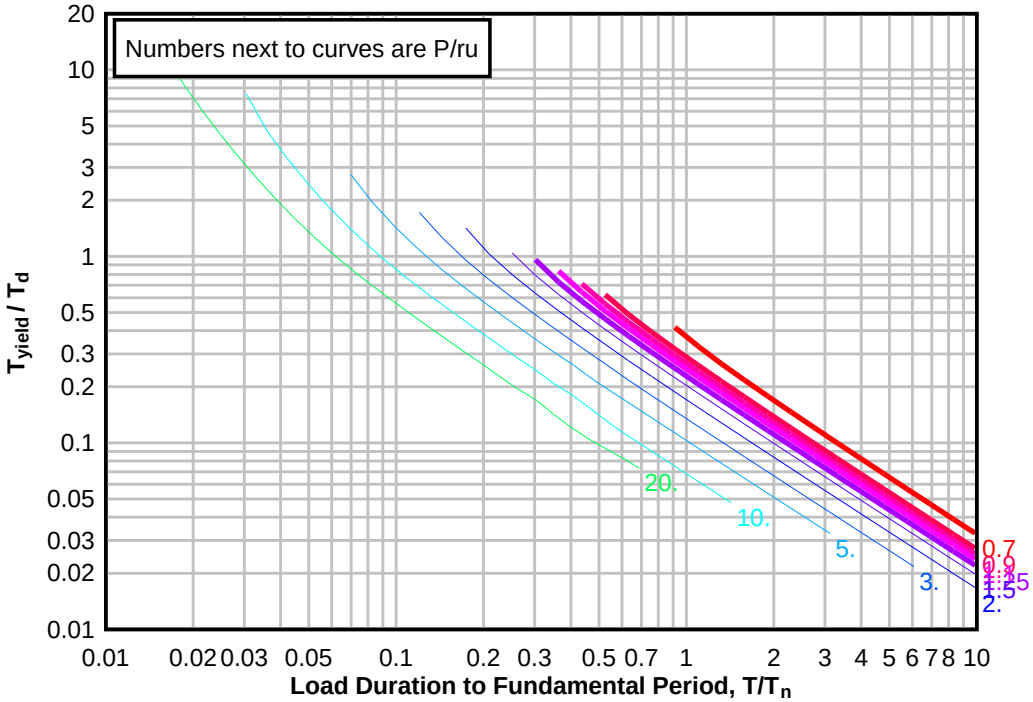


Figure 3-69(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.147, C_2 = 1.7)

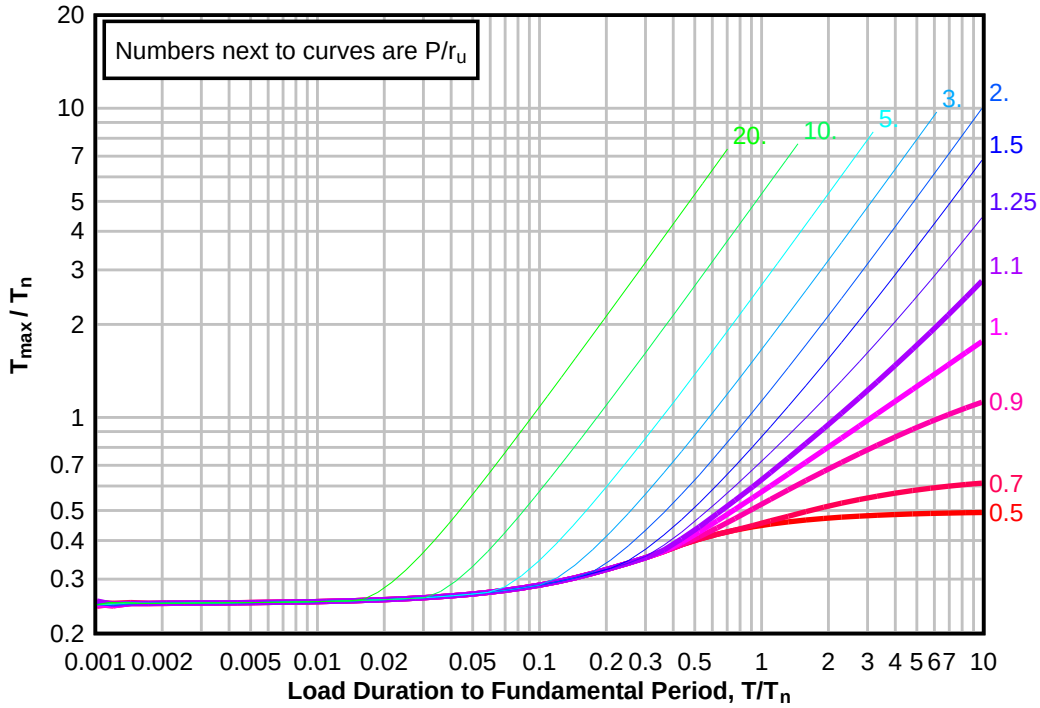


Figure 3-69(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.147, C2 = 1.7)

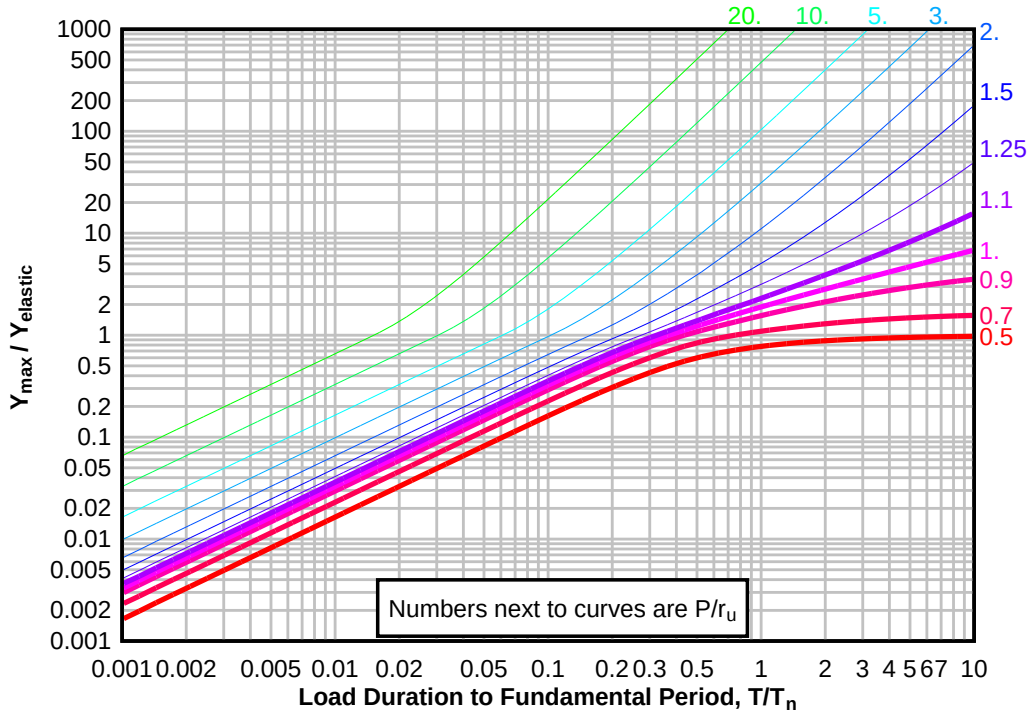


Figure 3-69(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.147, C2 = 1.7), cont.

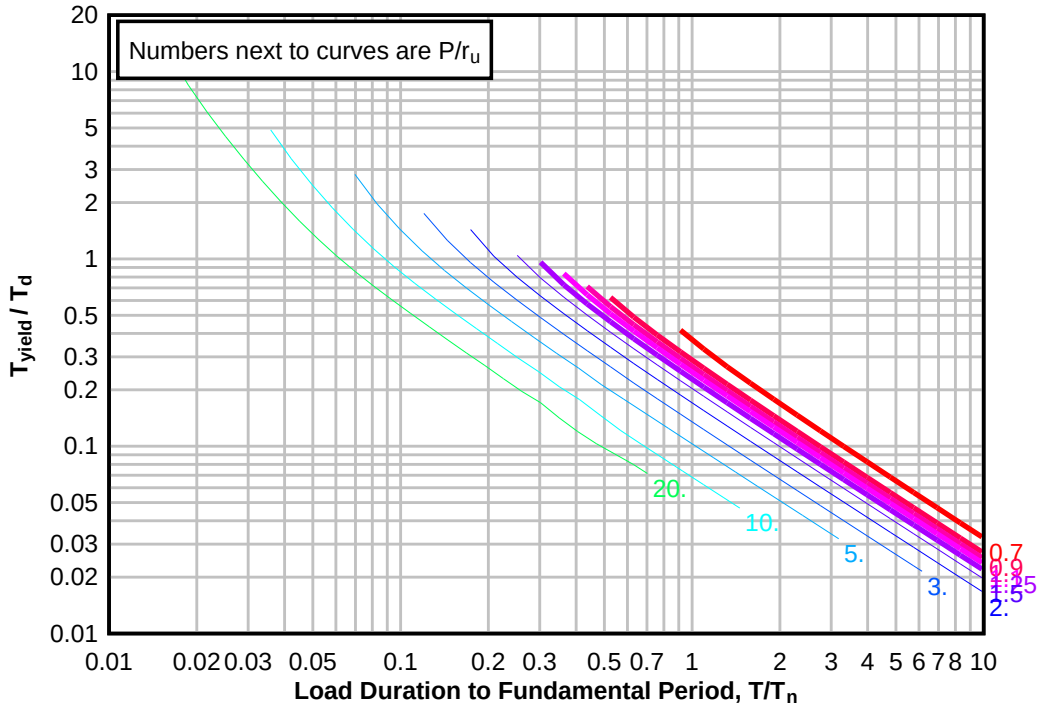


Figure 3-70(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.100, C_2 = 1.7)

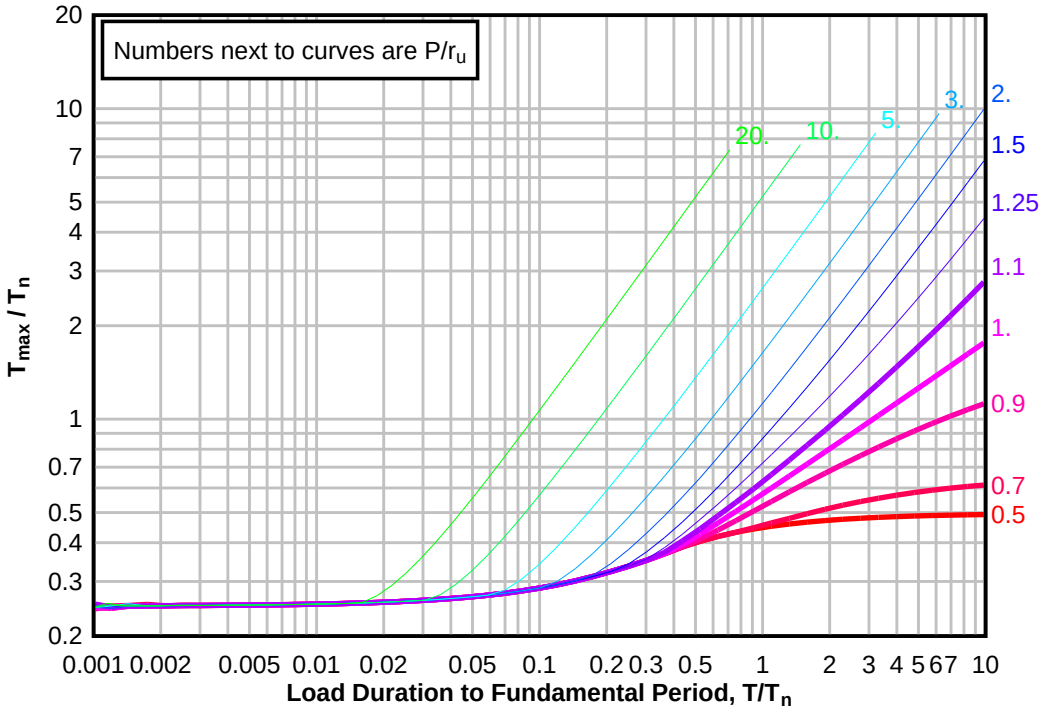


Figure 3-70(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.100, C2 = 1.7)

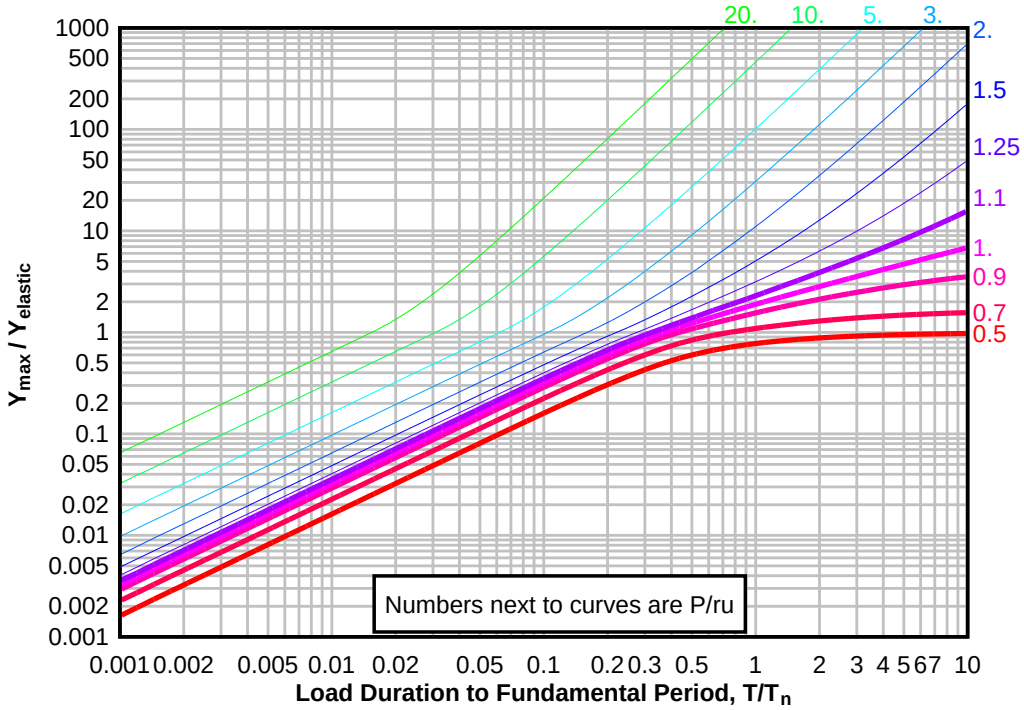


Figure 3-70(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.100, C2 = 1.7)

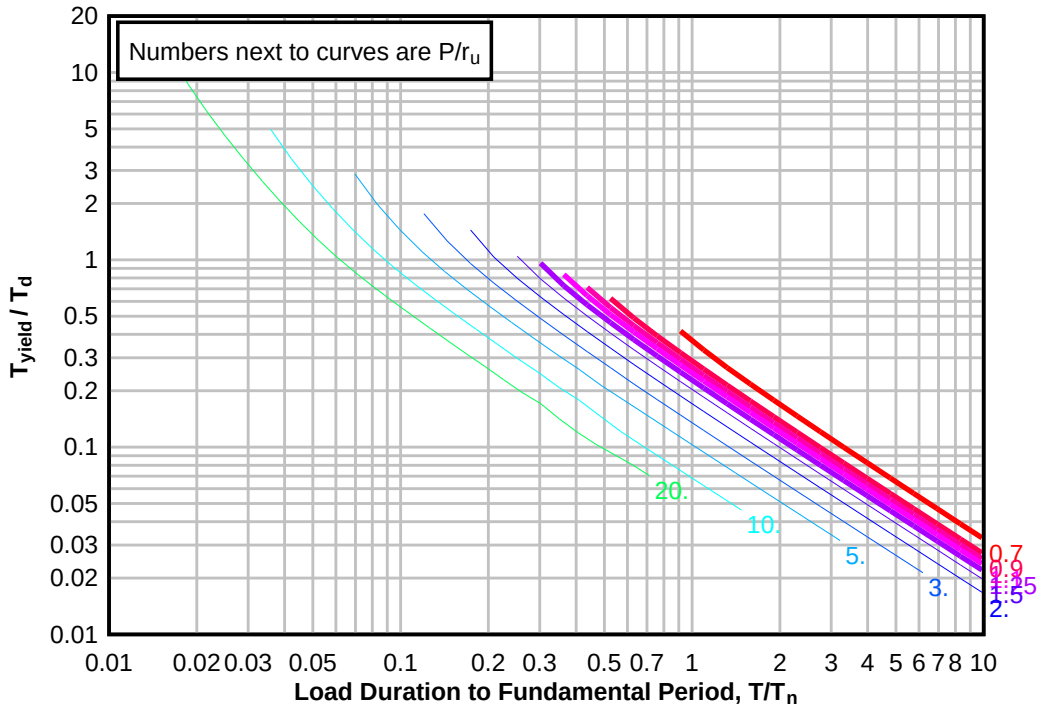


Figure 3-71(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.056, C_2 = 1.7)

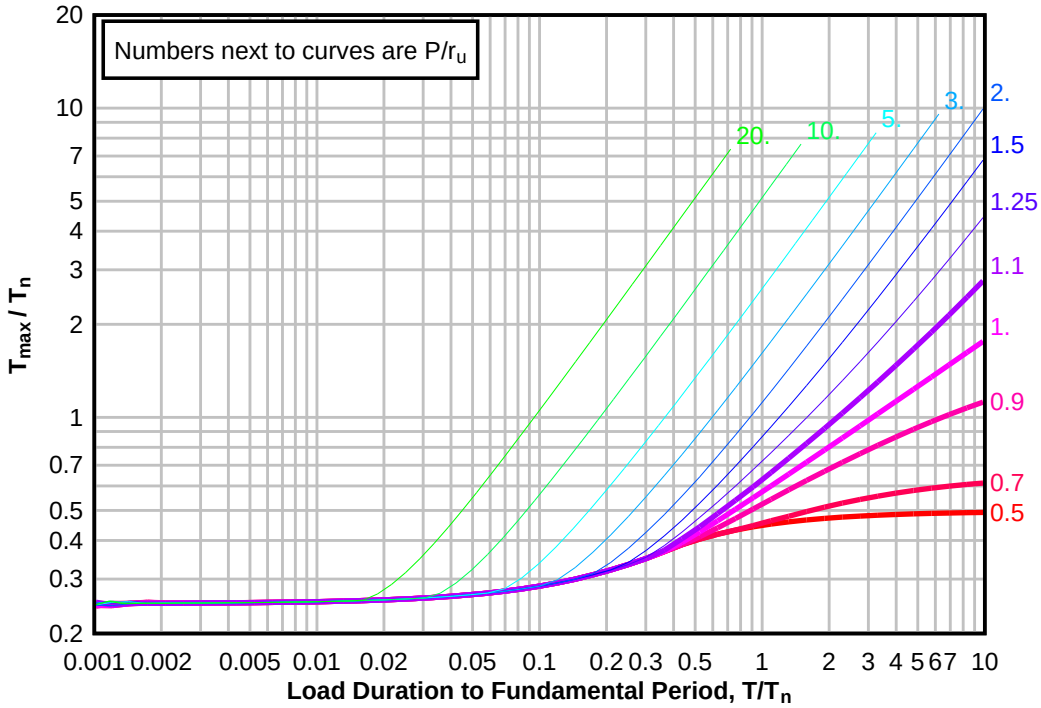


Figure 3-71(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.056, C2 = 1.7)

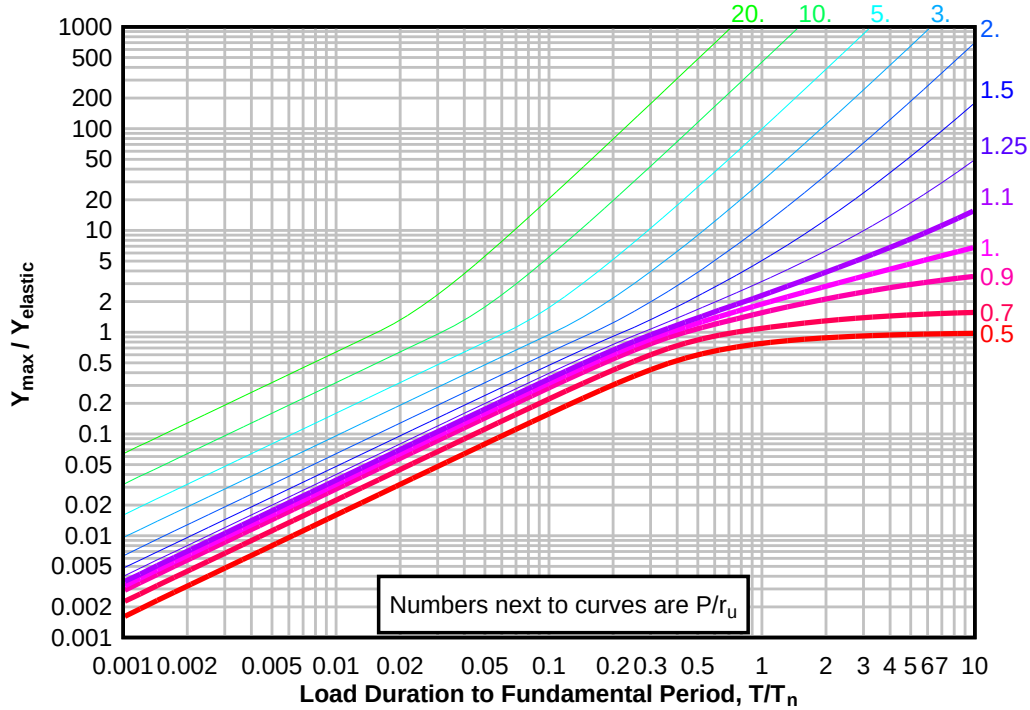


Figure 3-71(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.056, C2 = 1.7)

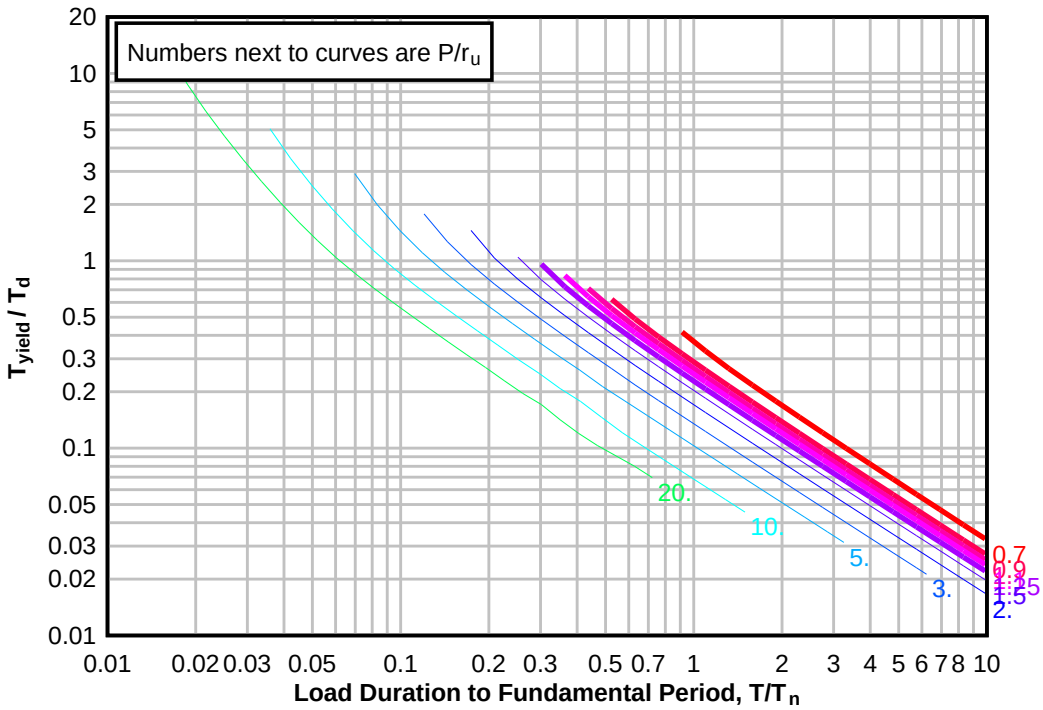


Figure 3-72(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.032, C_2 = 1.7)

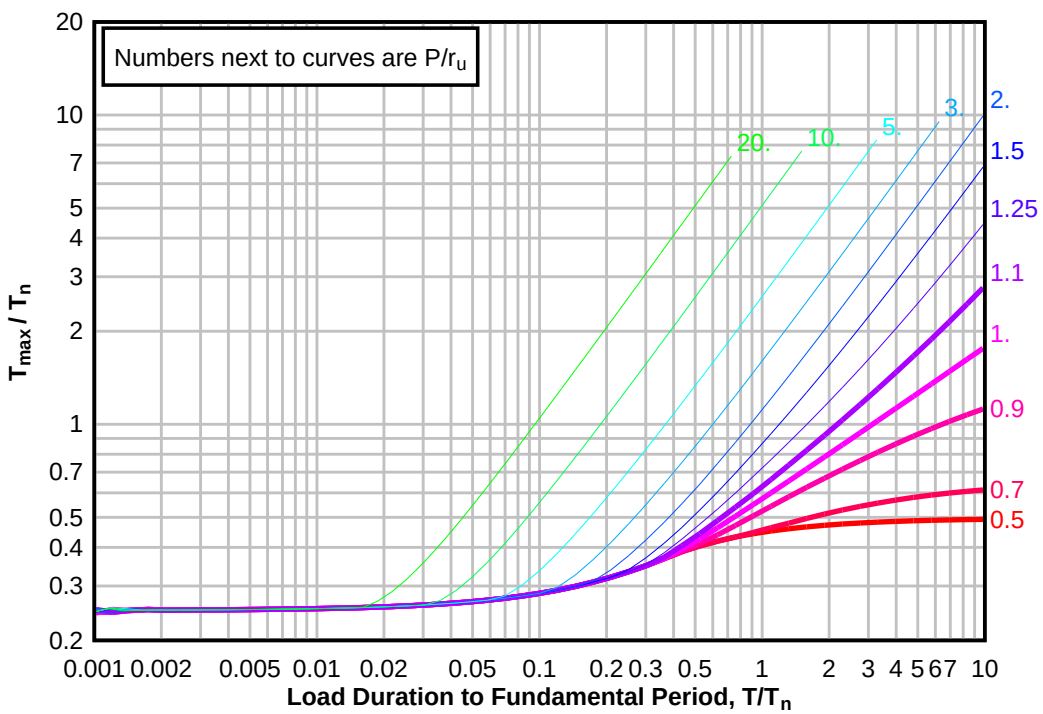


Figure 3-72(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.032, C2 = 1.7)

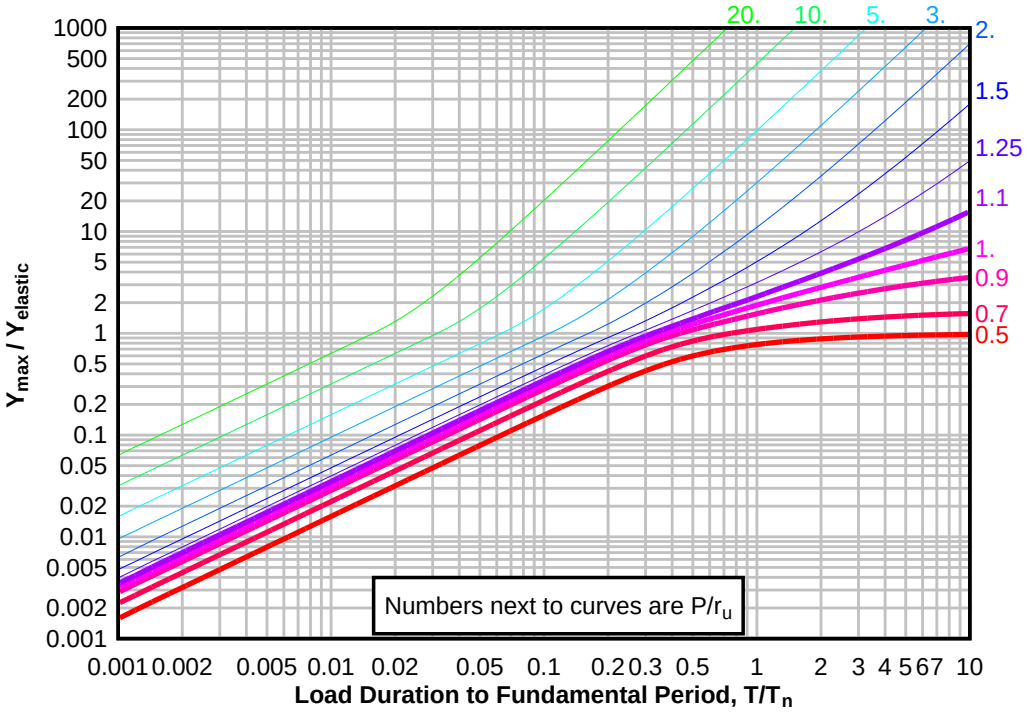


Figure 3-72(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.032, C2 = 1.7)

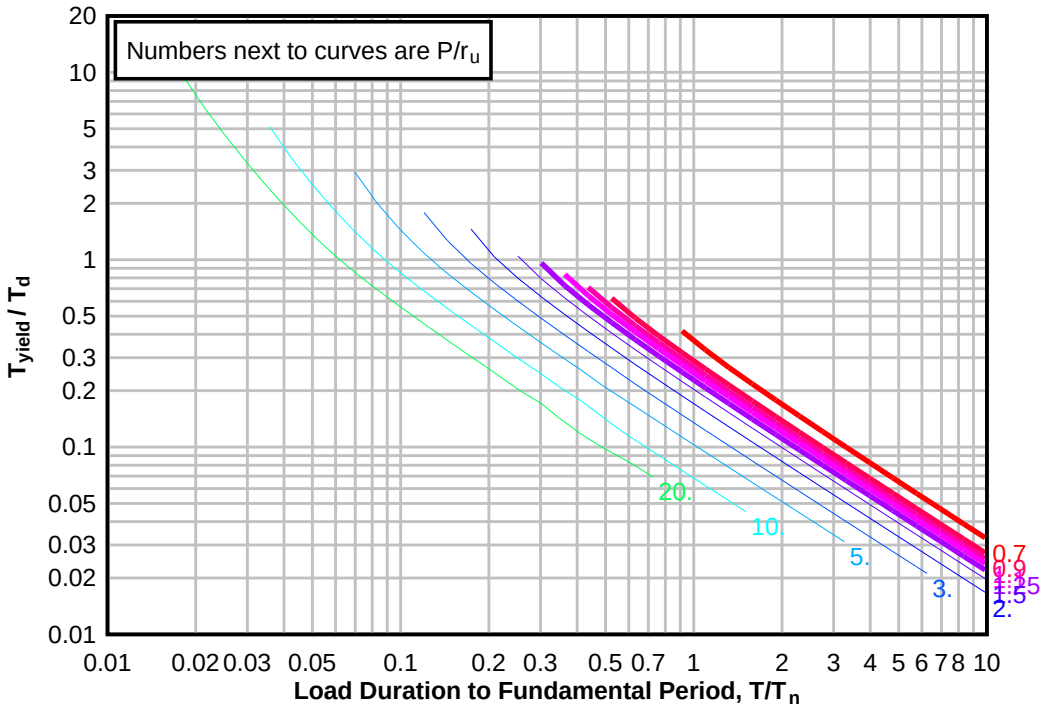


Figure 3-73(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.018, C_2 = 1.7)

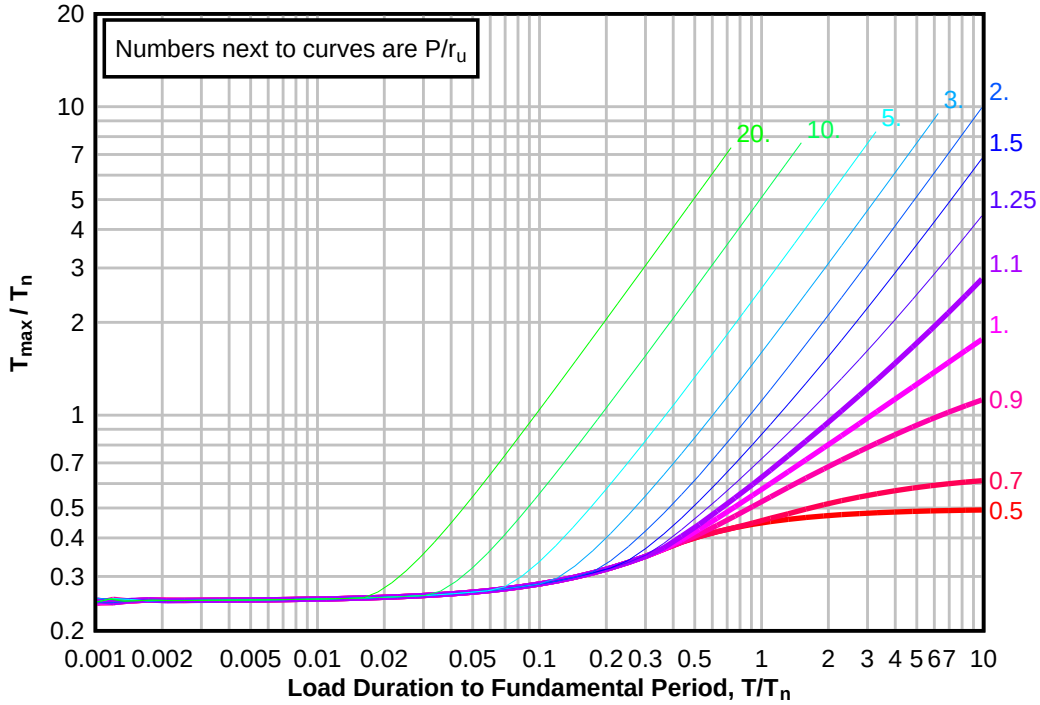


Figure 3-73(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.018, C2 = 1.7)

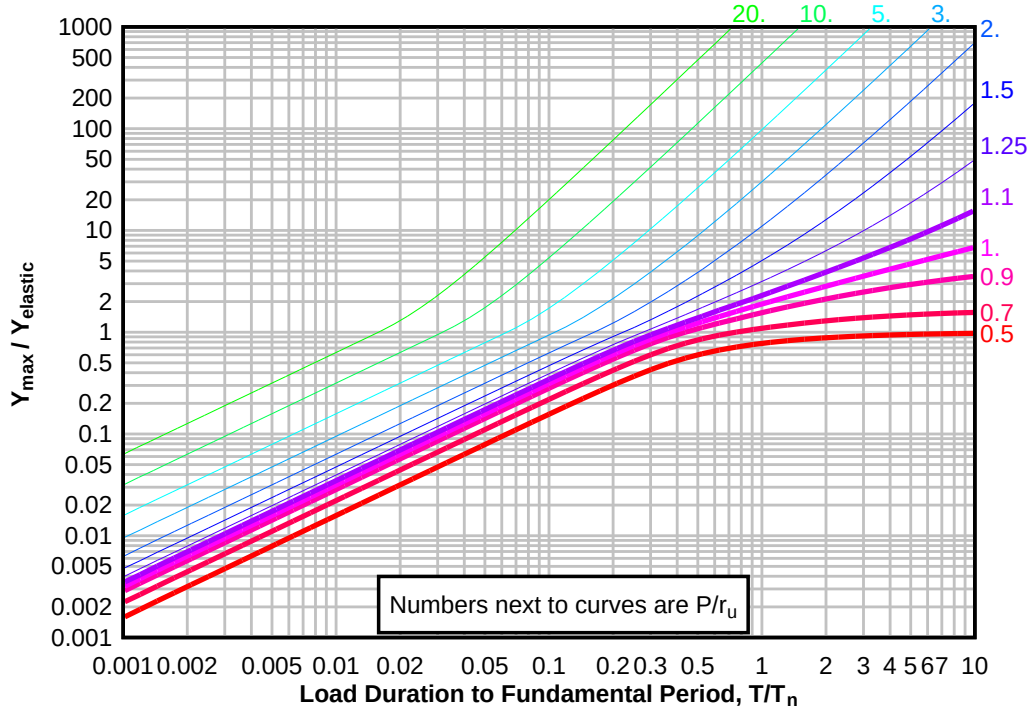


Figure 3-73(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.018, C2 = 1.7)

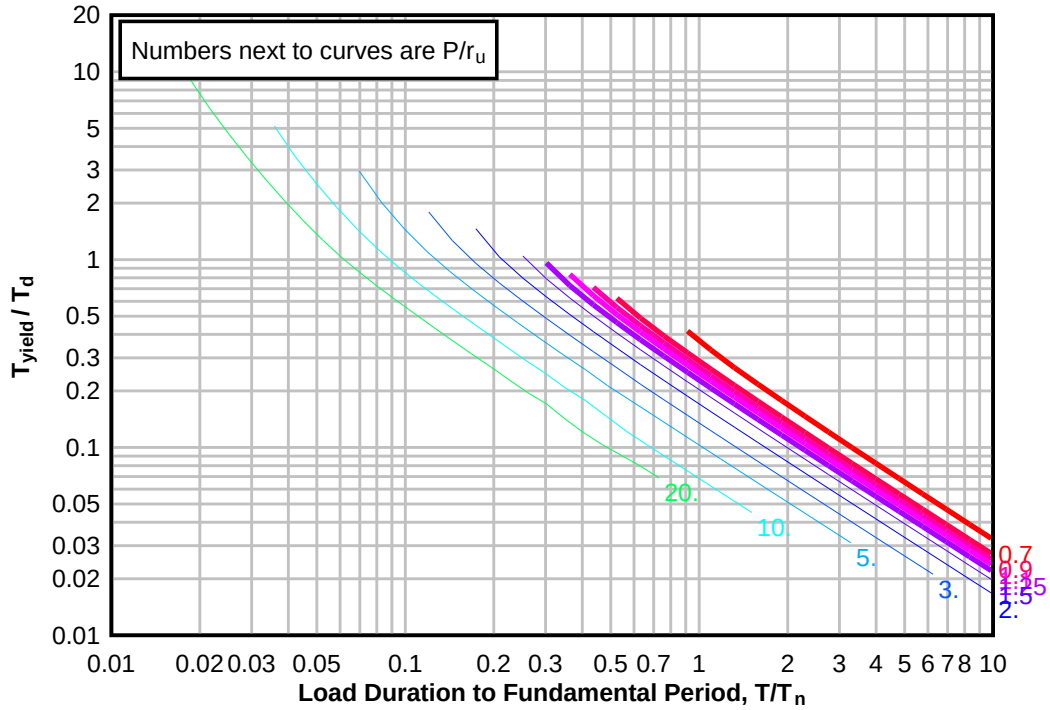


Figure 3-74(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.010, C_2 = 1.7)

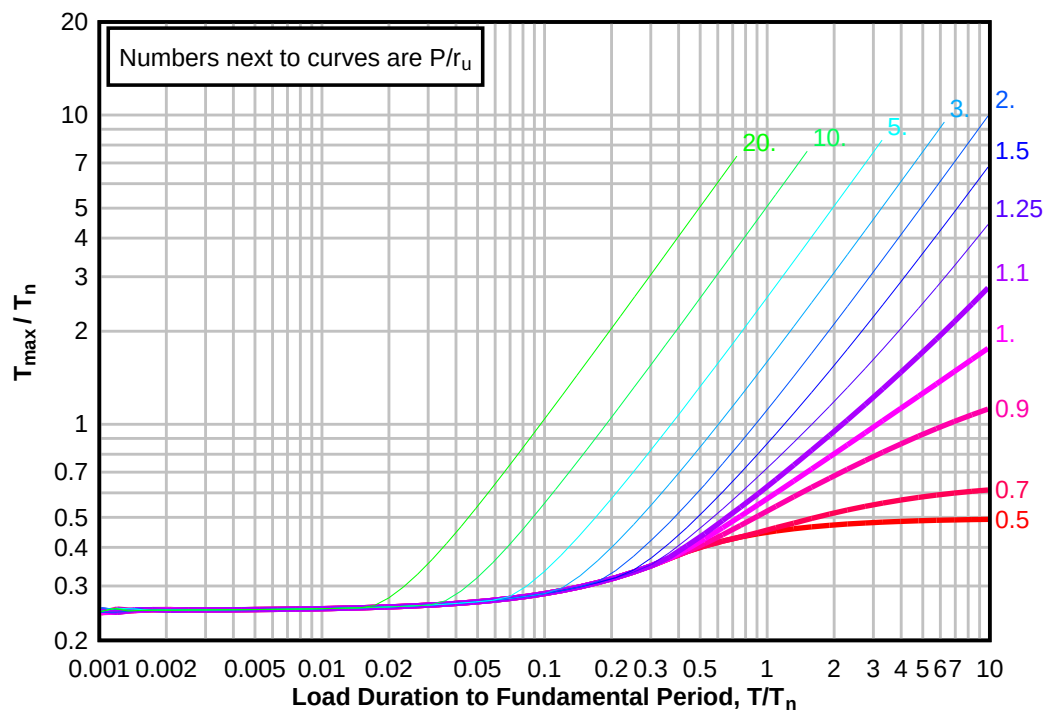


Figure 3-74(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.010, C2 = 1.7)

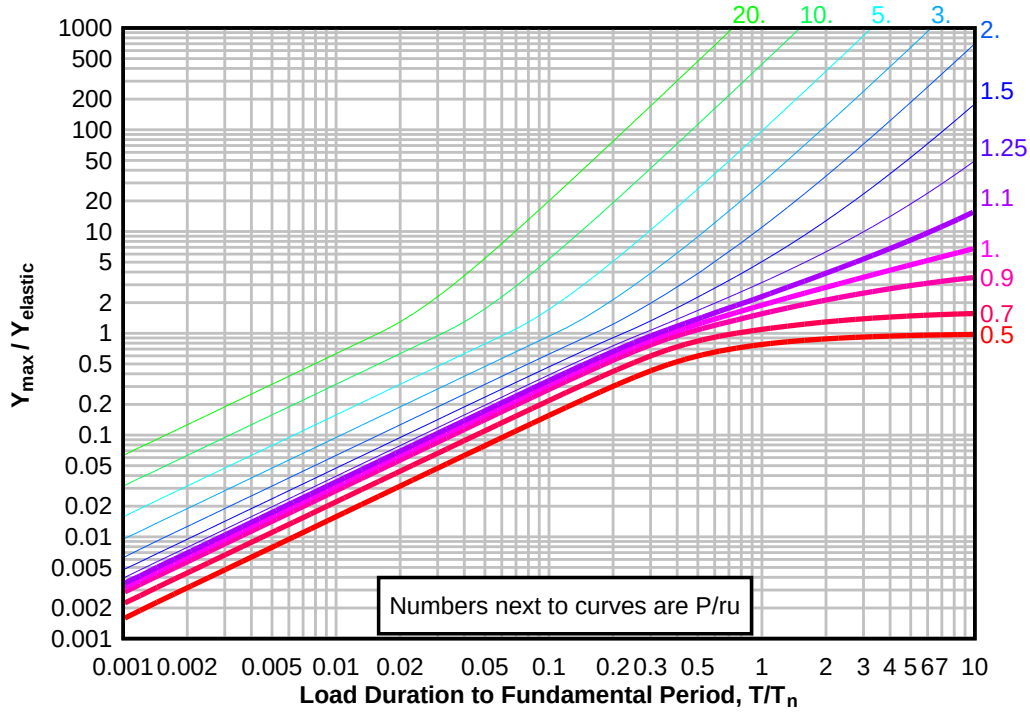


Figure 3-74(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.010, C2 = 1.7)

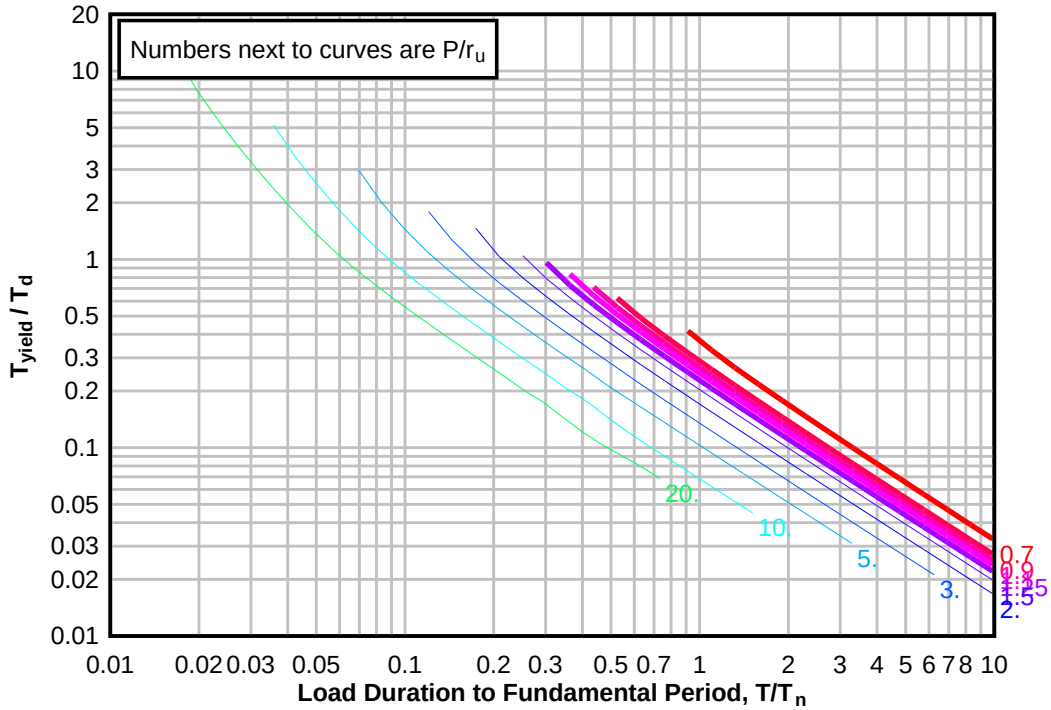


Figure 3-75(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.681, C_2 = 3.0)

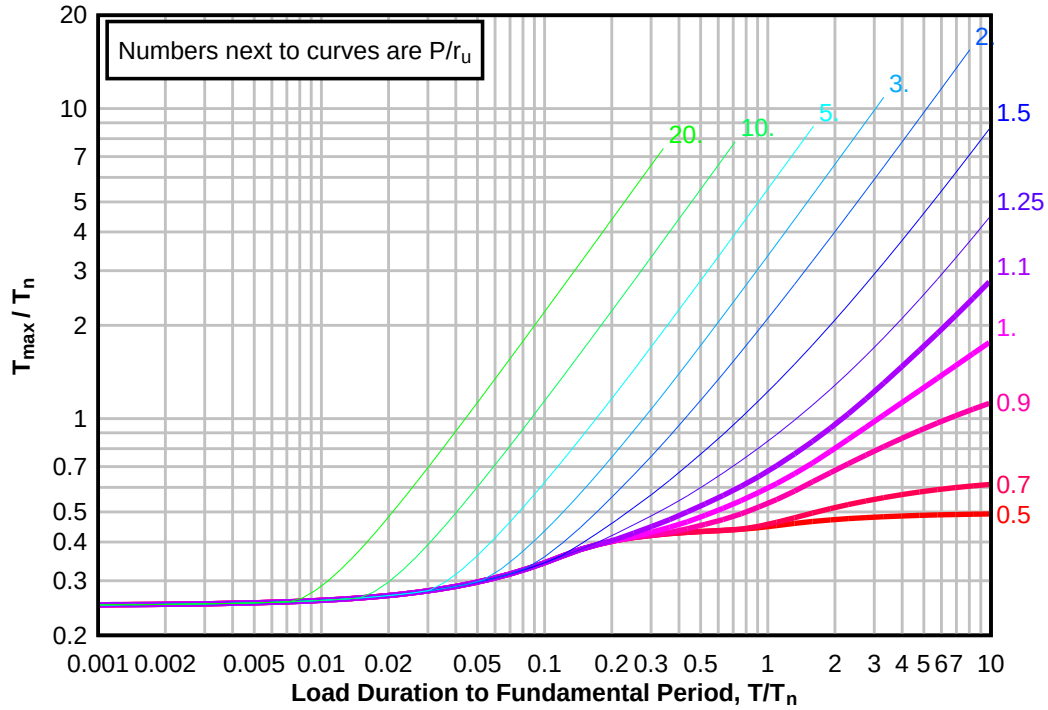


Figure 3-75(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.681, C2 = 3.0)

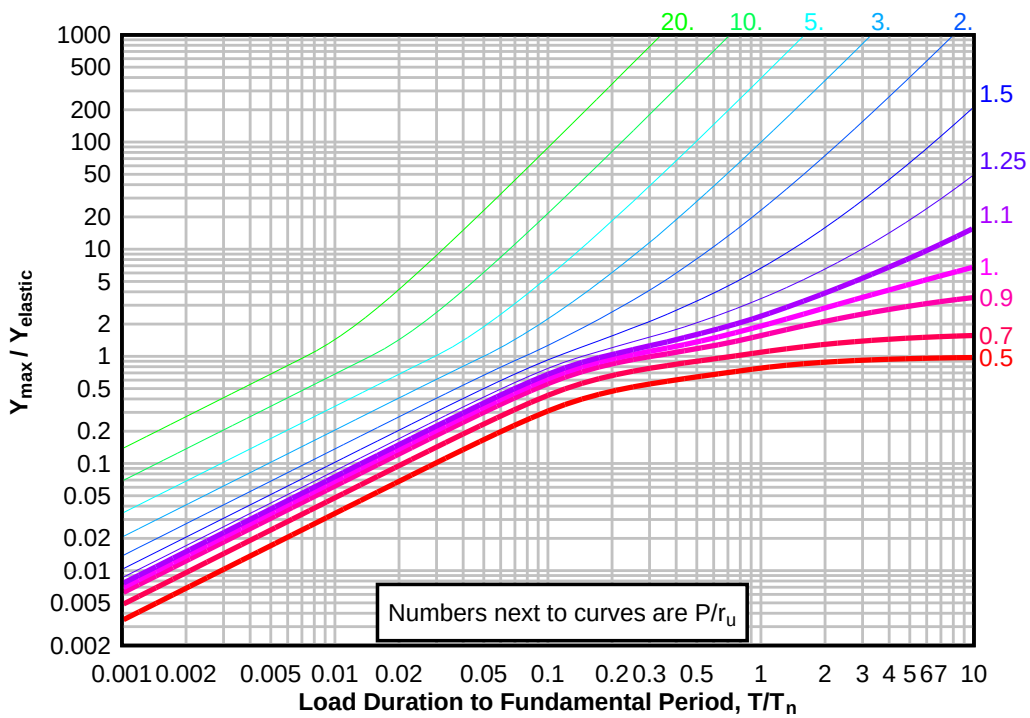


Figure 3-75(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.681, C2 = 3.0)

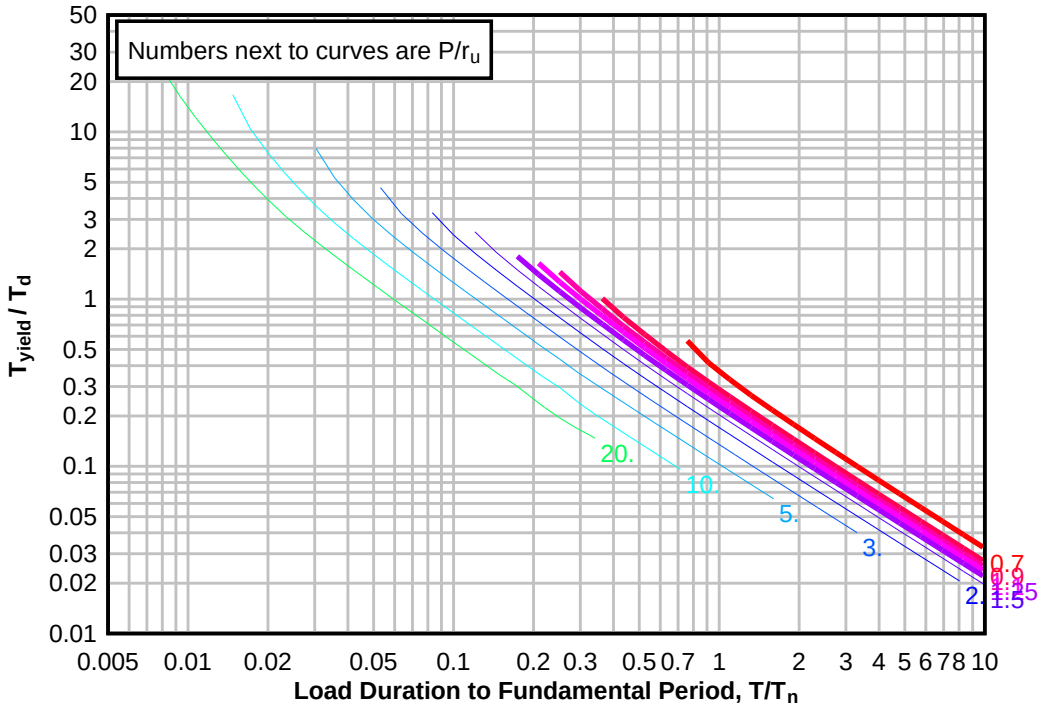


Figure 3-76(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.464, C_2 = 3.0)

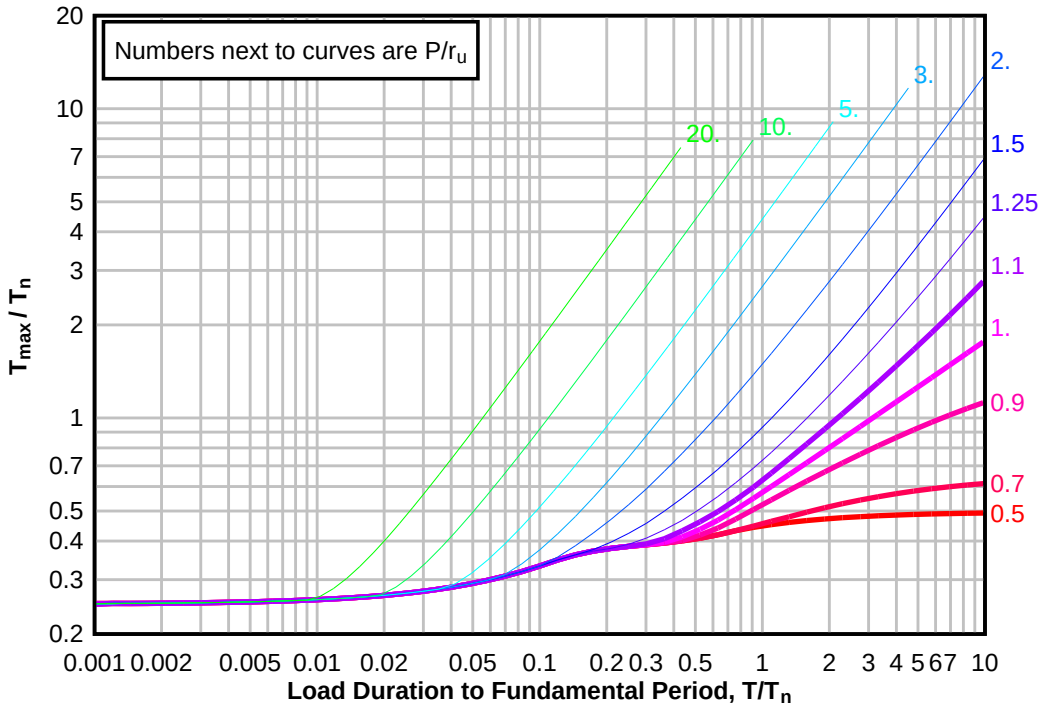


Figure 3-76(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.464, C2 = 3.0)

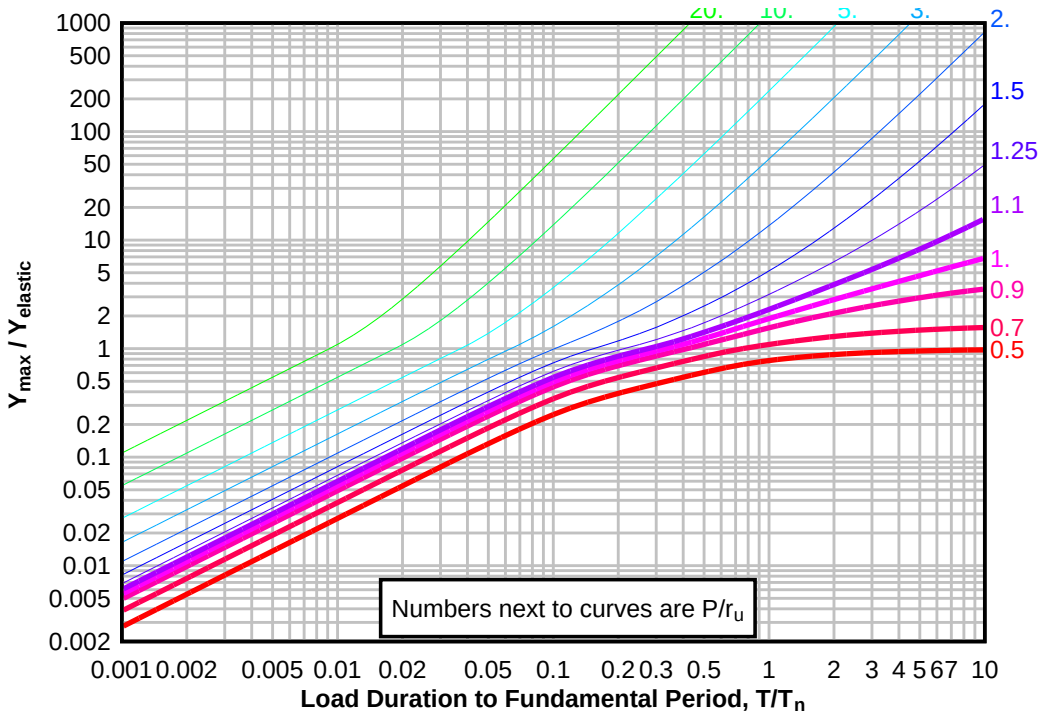


Figure 3-76(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.464, C2 = 3.0)

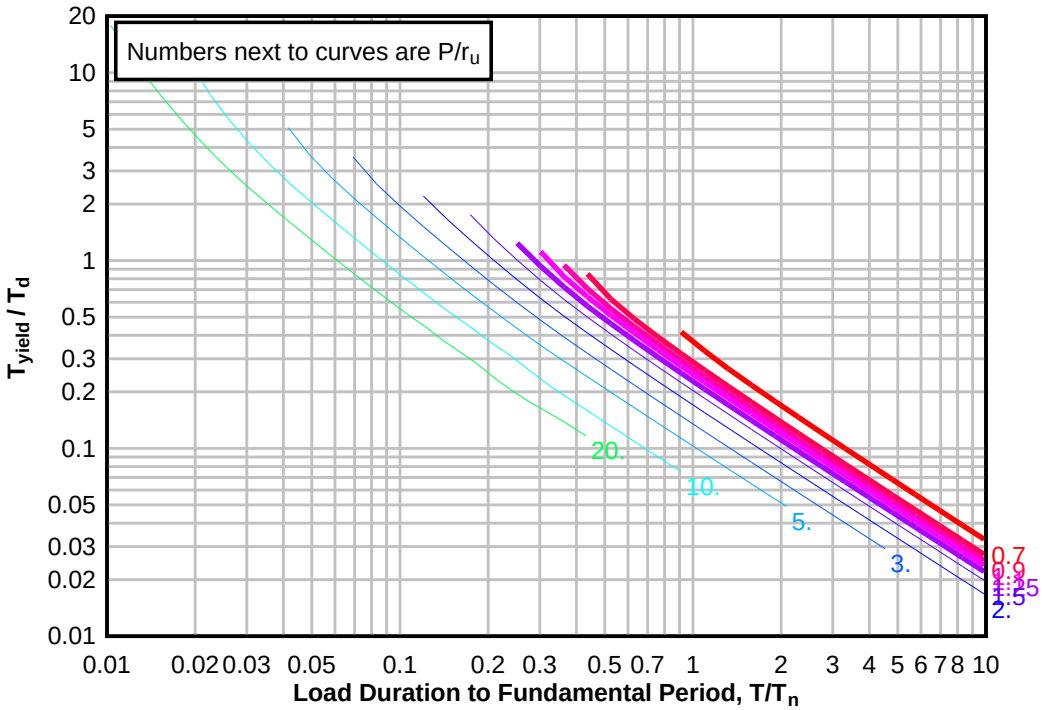


Figure 3-77(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.316, C_2 = 3.0)

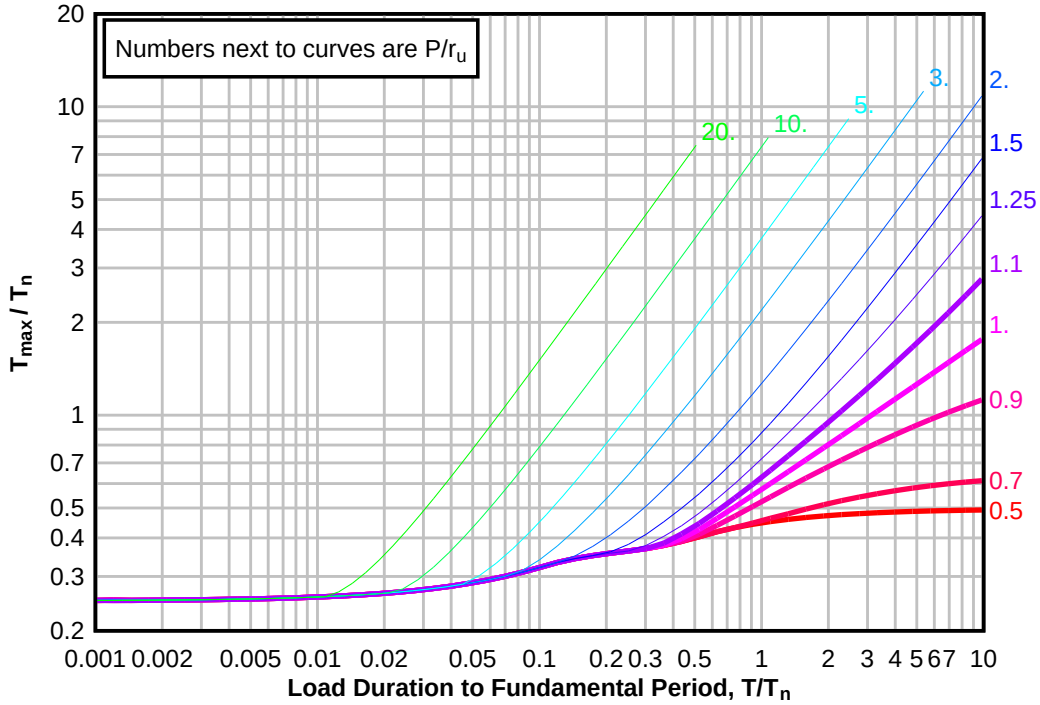


Figure 3-77(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.316, C2 = 3.0)

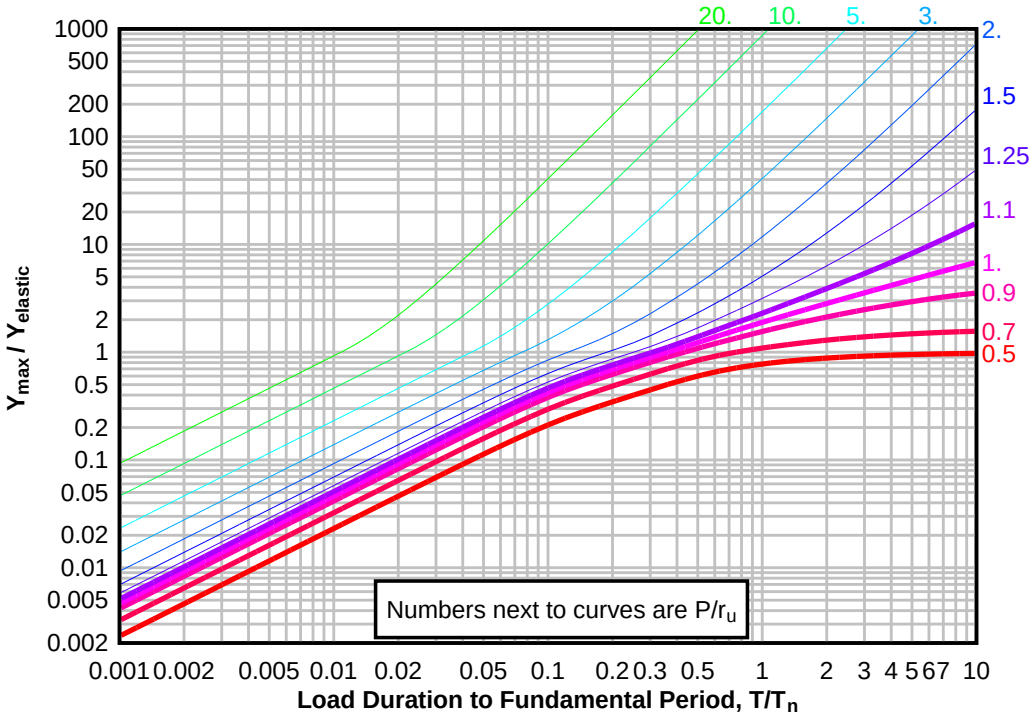


Figure 3-77(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.316, C2 = 3.0)

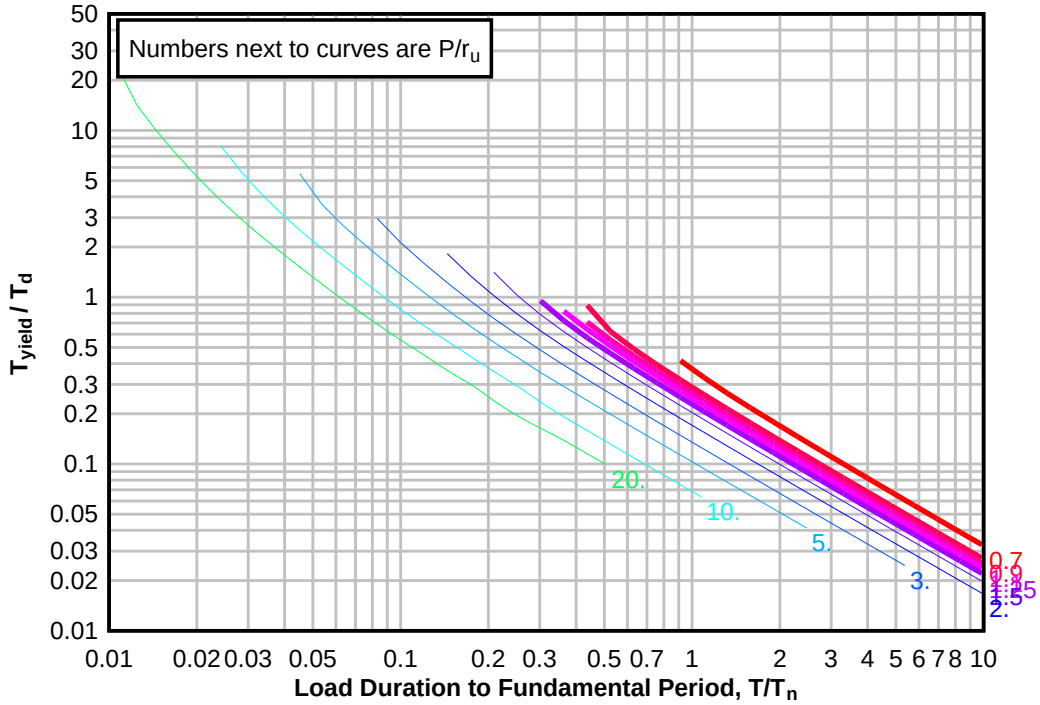


Figure 3-78(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.215, C_2 = 3.0)

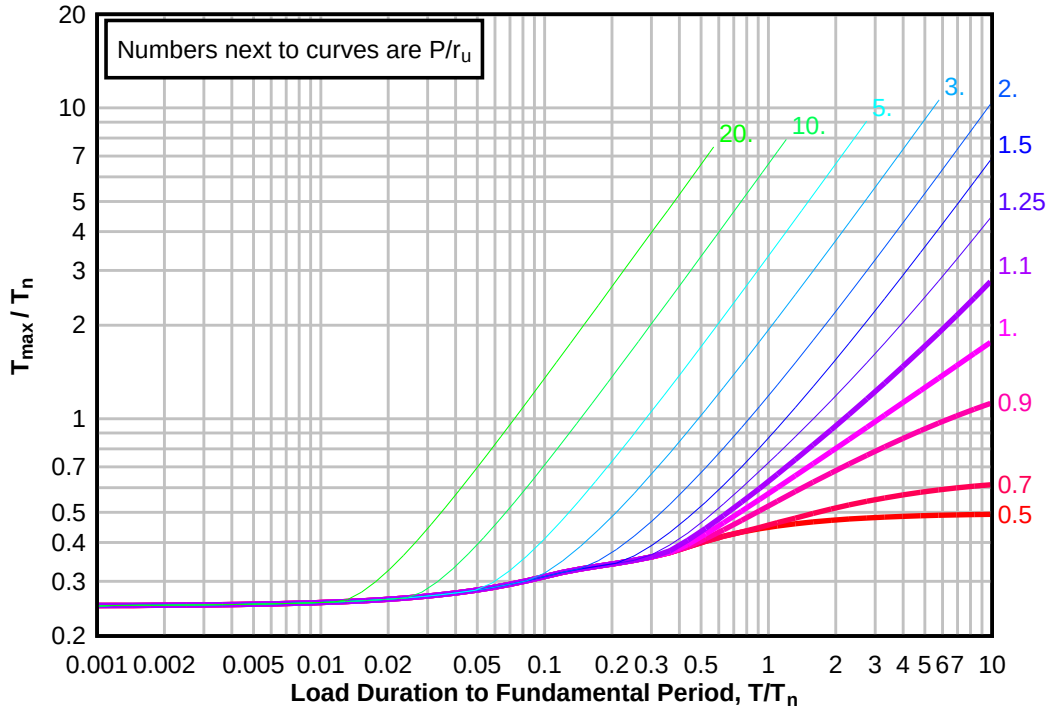


Figure 3-78(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.215, C2 = 3.0)

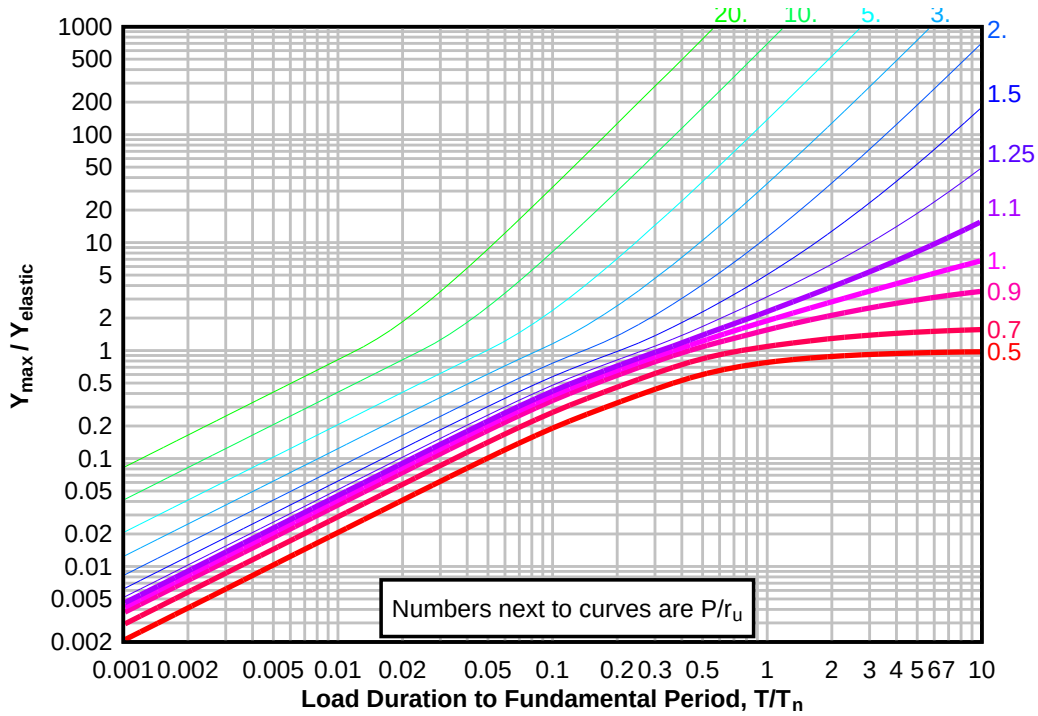


Figure 3-78(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.215, C2 = 3.0)

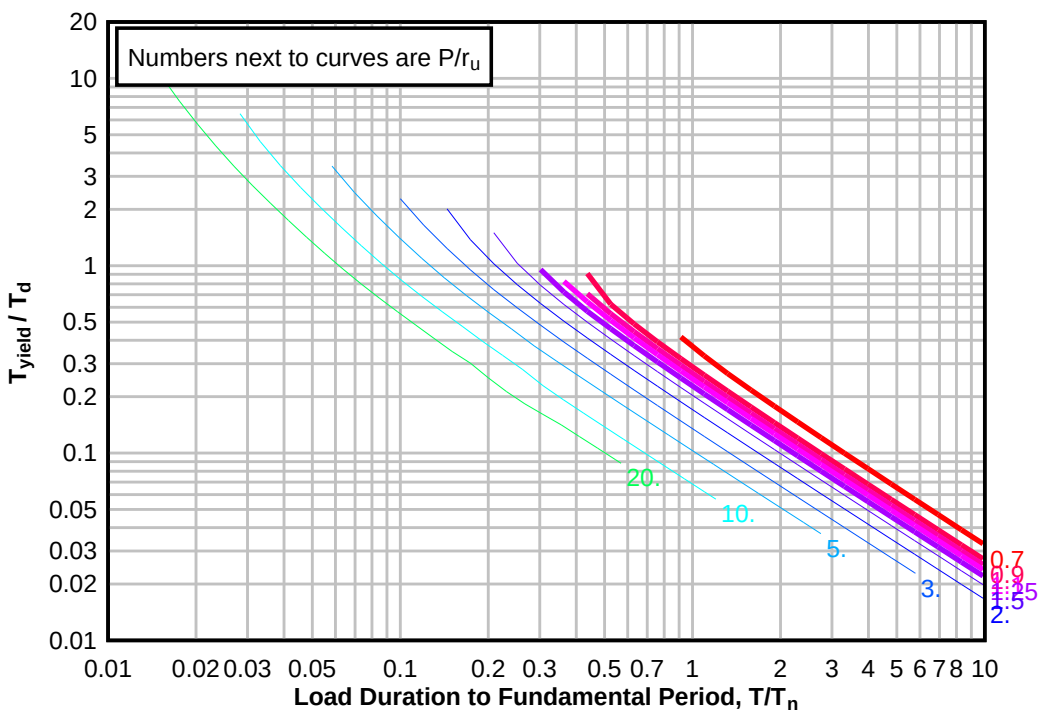


Figure 3-79(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.147, C_2 = 3.0)

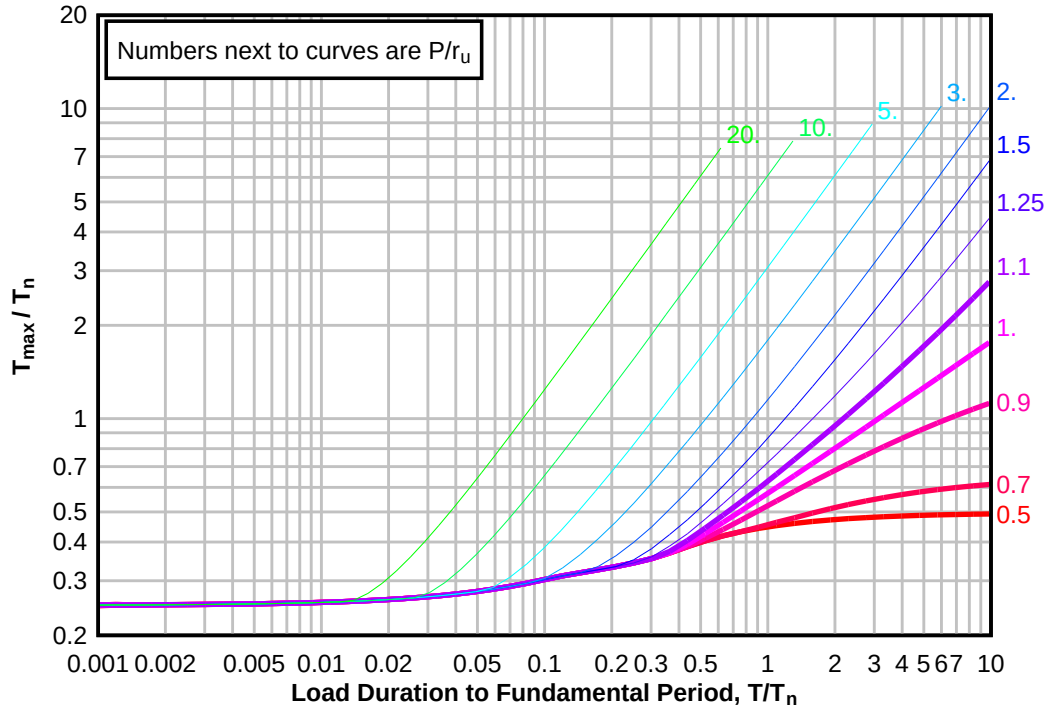


Figure 3-79(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.147, C2 = 3.0)

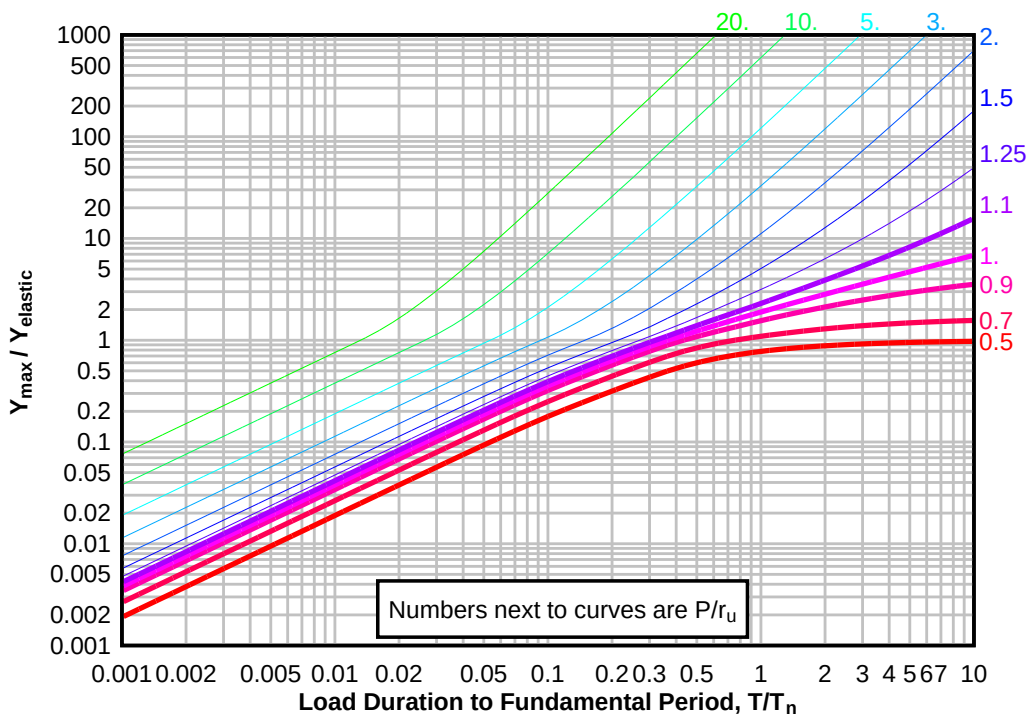


Figure 3-79(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.147, C2 = 3.0)

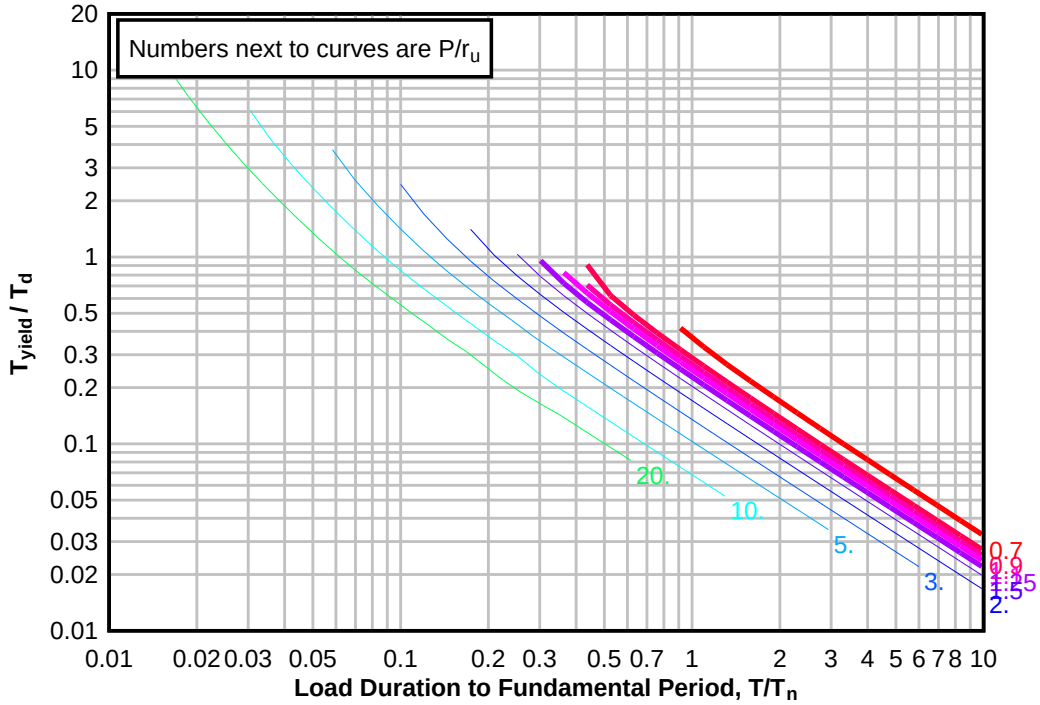


Figure 3-80(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.100, C_2 = 3.0)

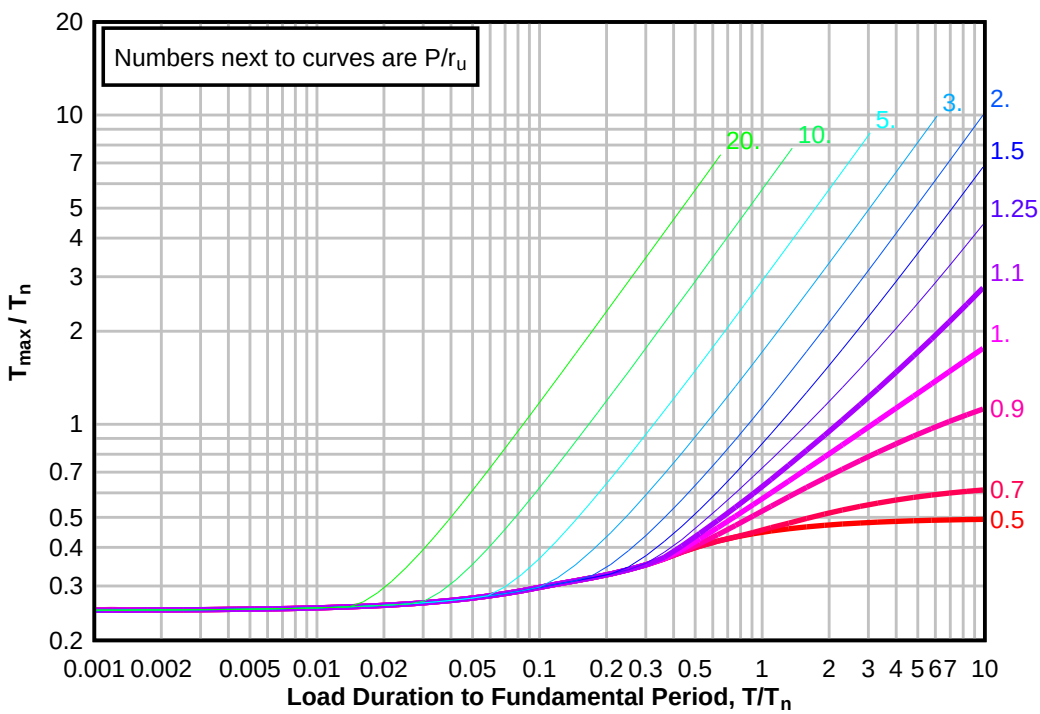


Figure 3-80(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.100, C2 = 3.0)

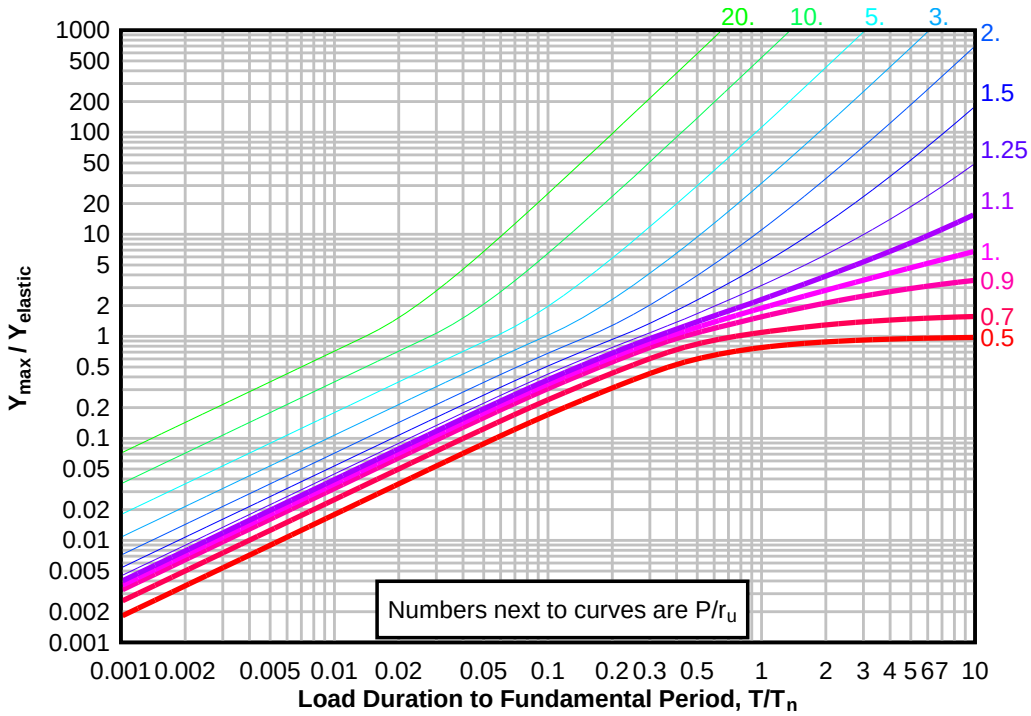


Figure 3-80(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.100, C2 = 3.0)

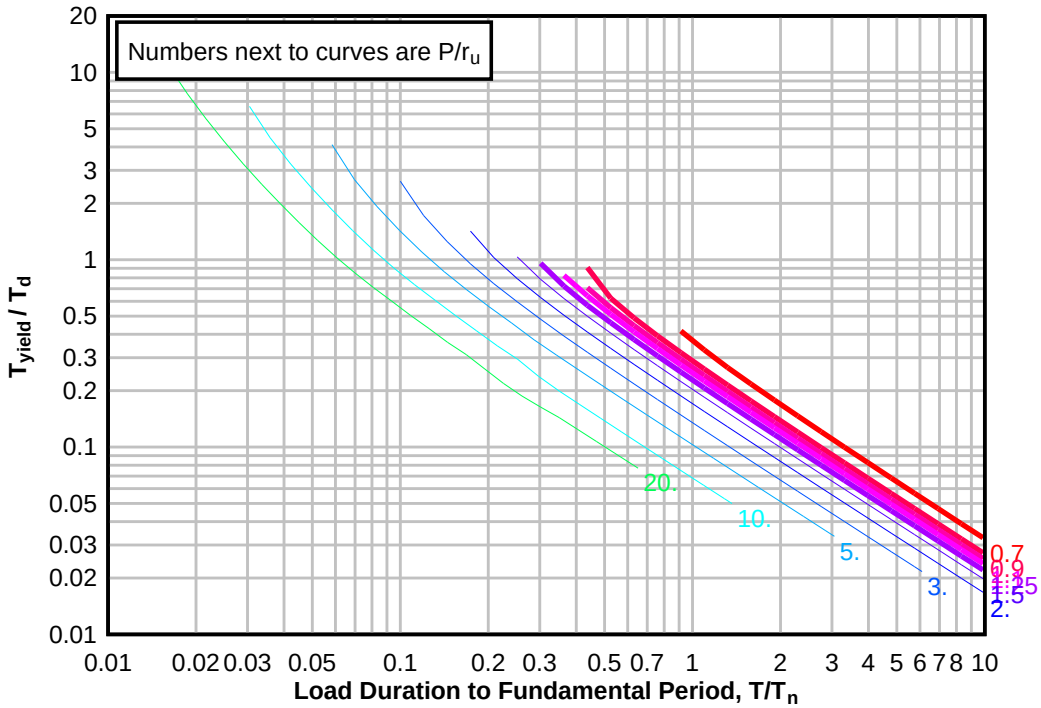


Figure 3-81(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.056, C_2 = 3.0)

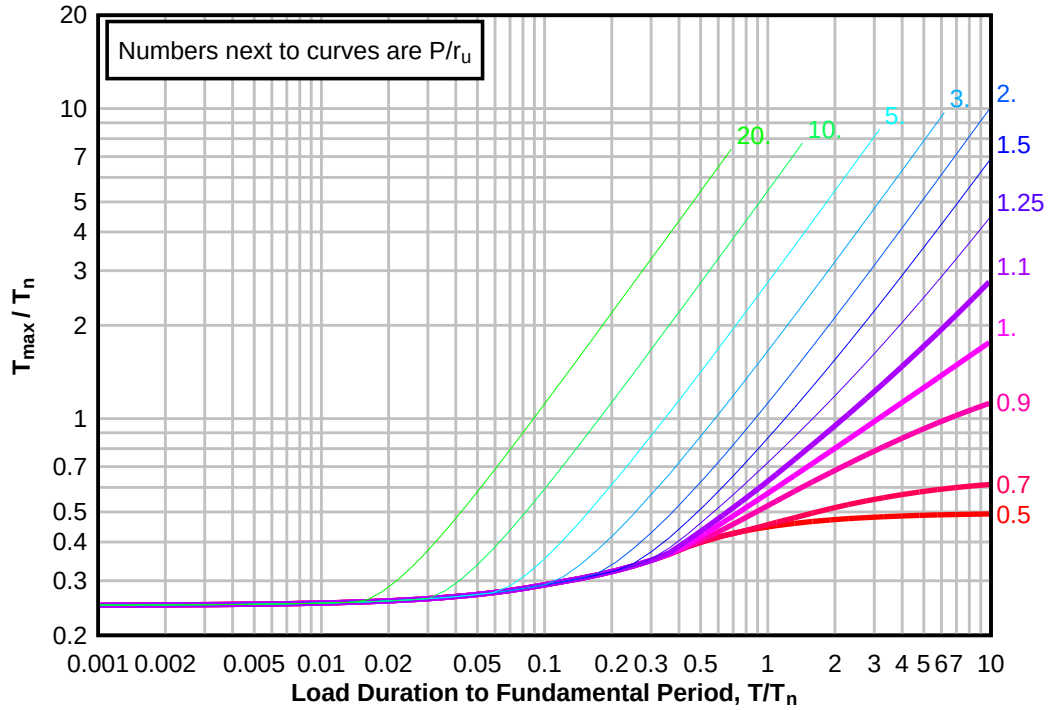


Figure 3-81(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.056, C2 = 3.0)

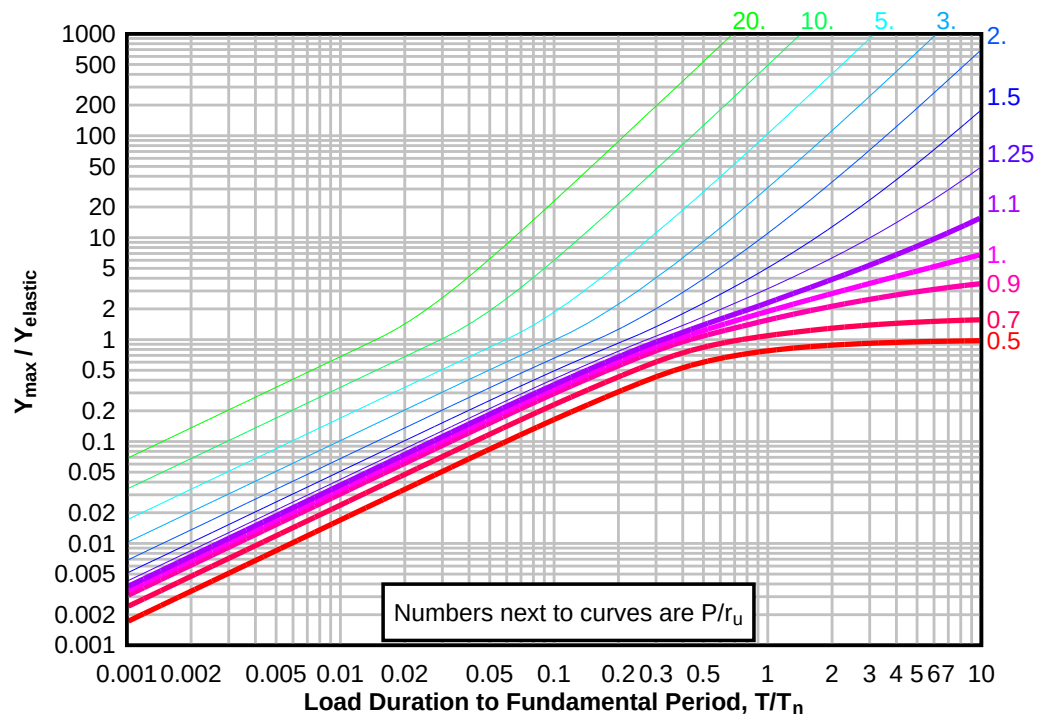


Figure 3-81(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.056, C2 = 3.0)

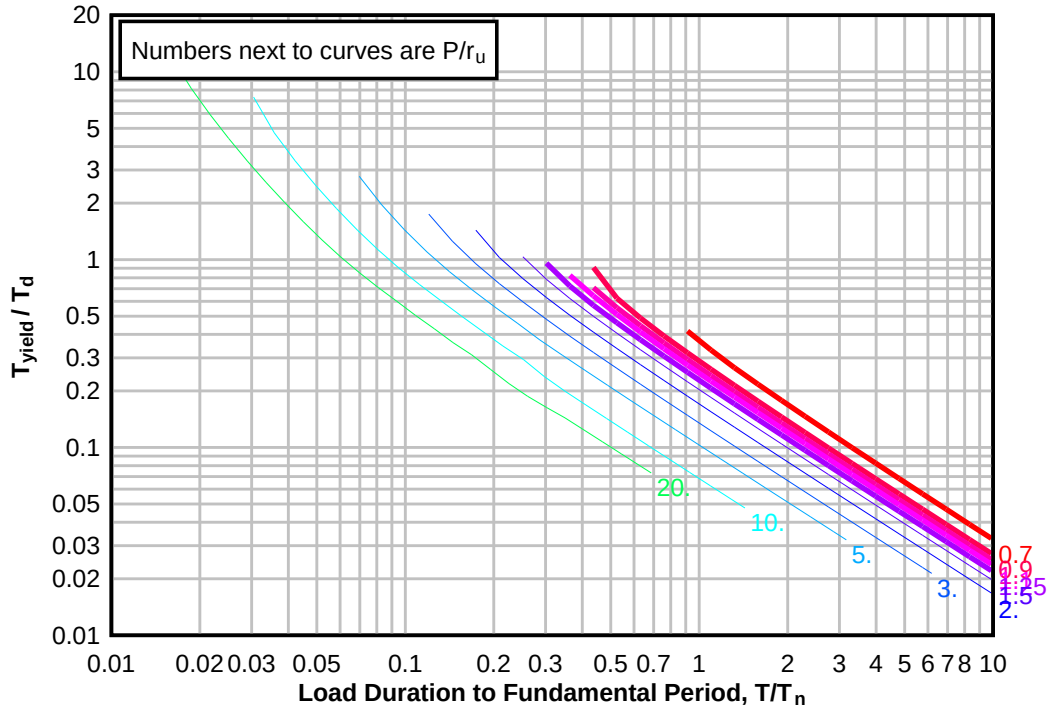


Figure 3-82(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.032, C_2 = 3.0)

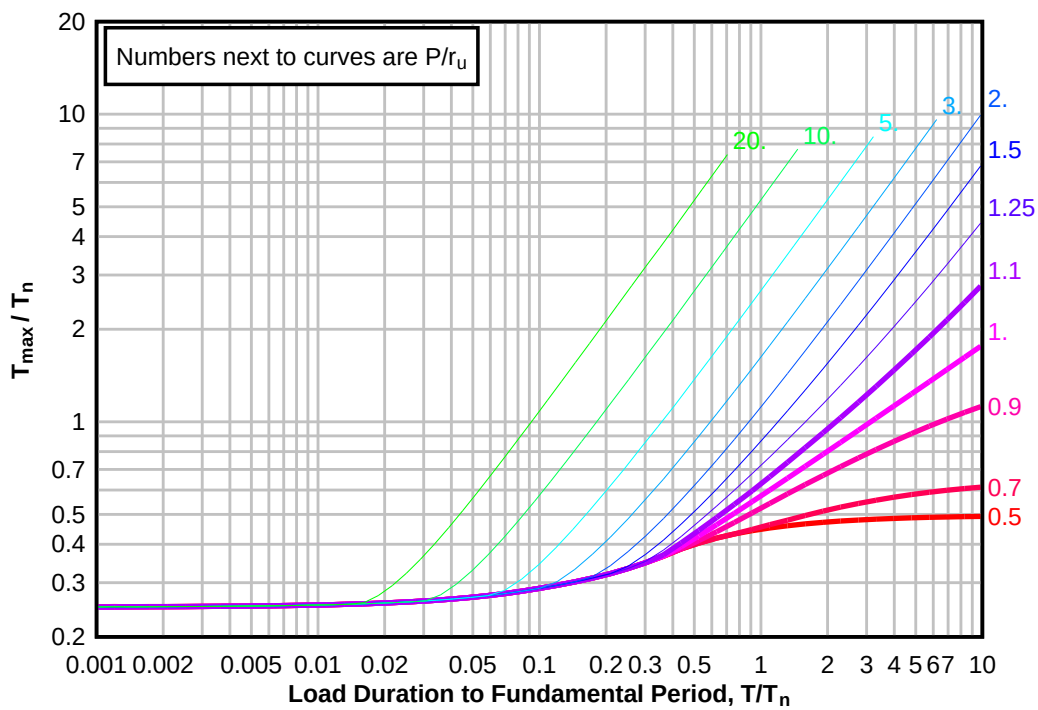


Figure 3-82(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.032, C2 = 3.0)

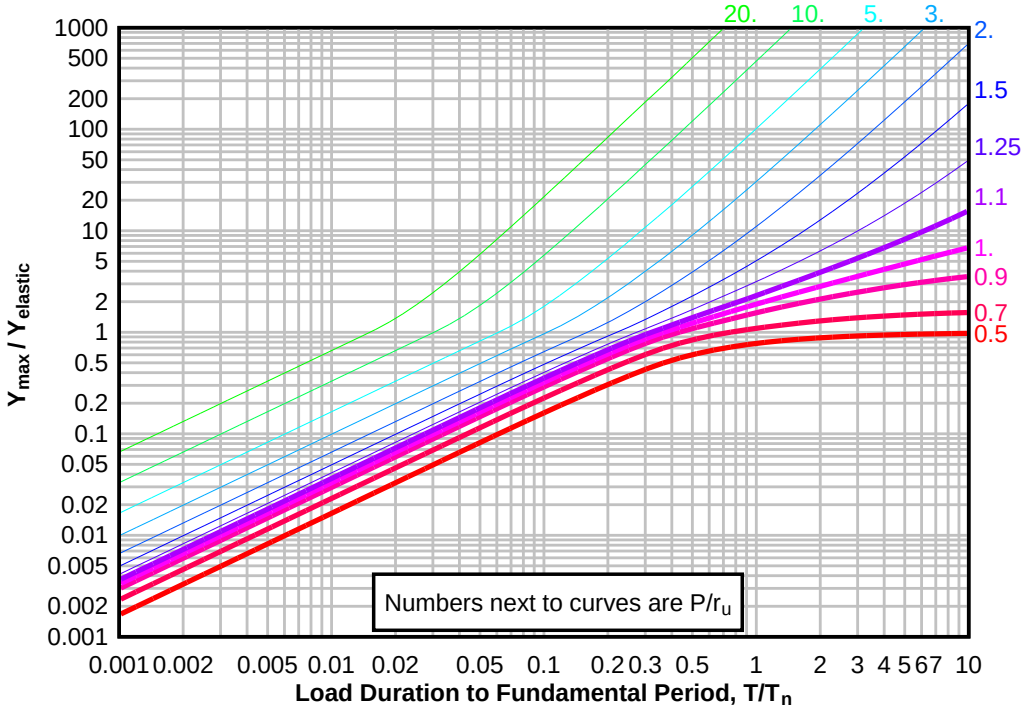


Figure 3-82(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.032, C2 = 3.0)

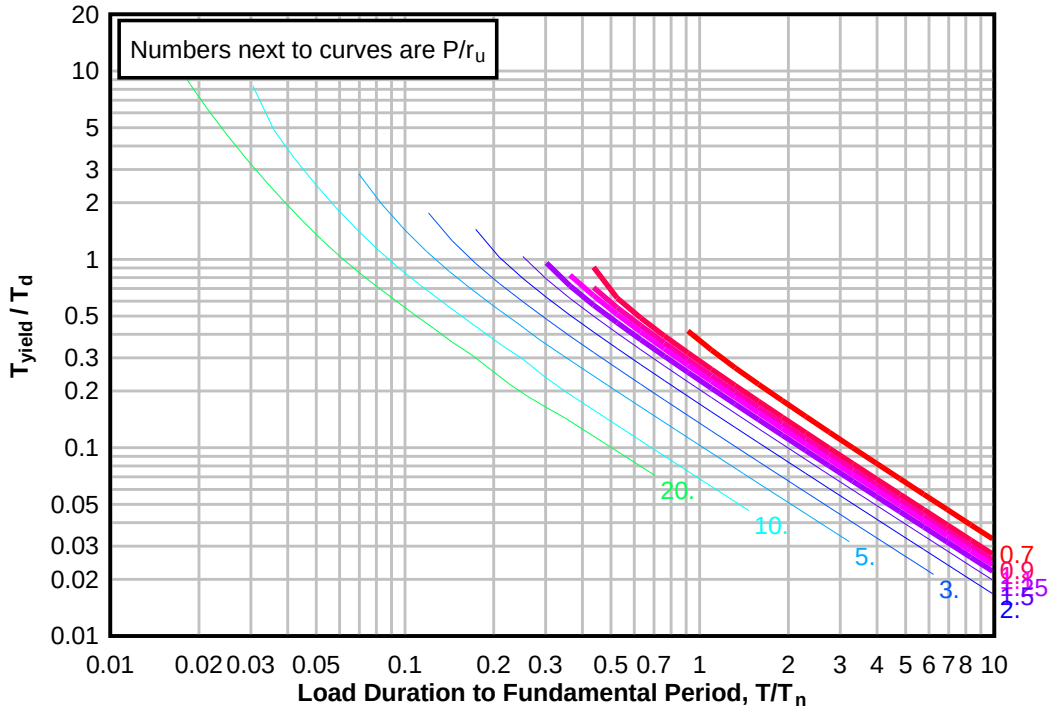


Figure 3-83(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.018, C_2 = 3.0)

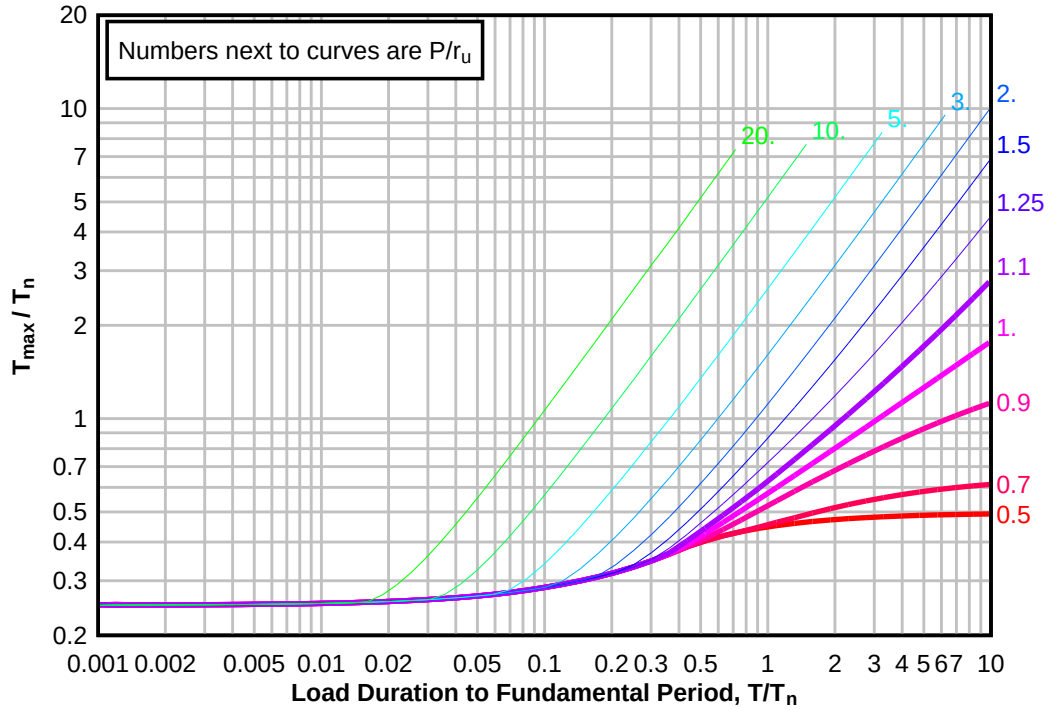


Figure 3-83(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.018, C2 = 3.0)

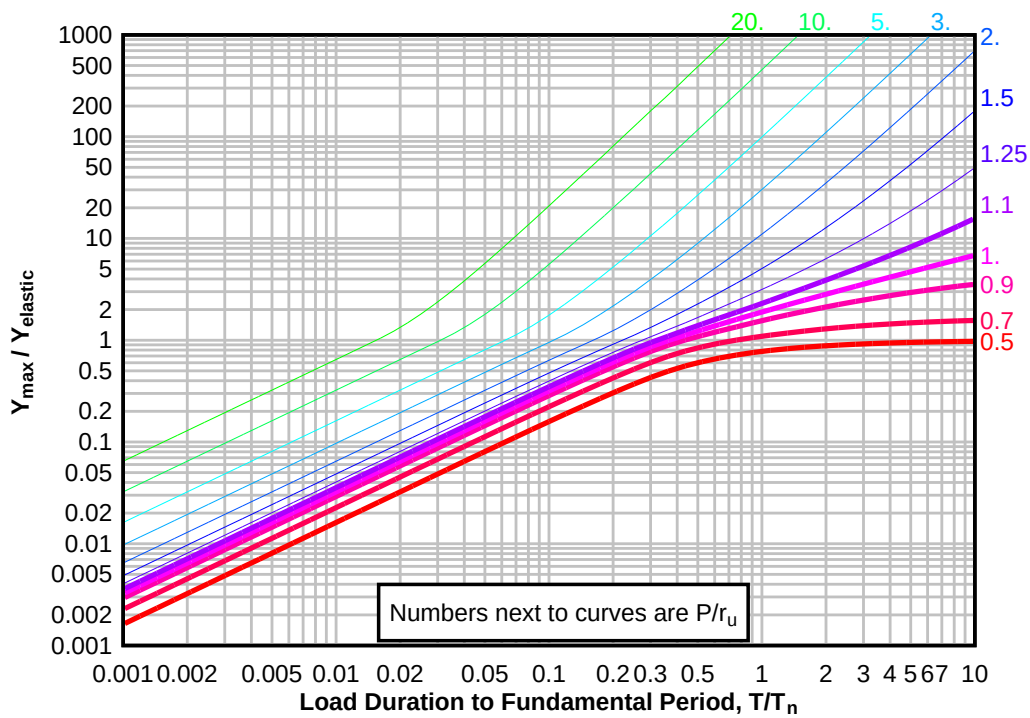


Figure 3-83(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.018, C2 = 3.0)

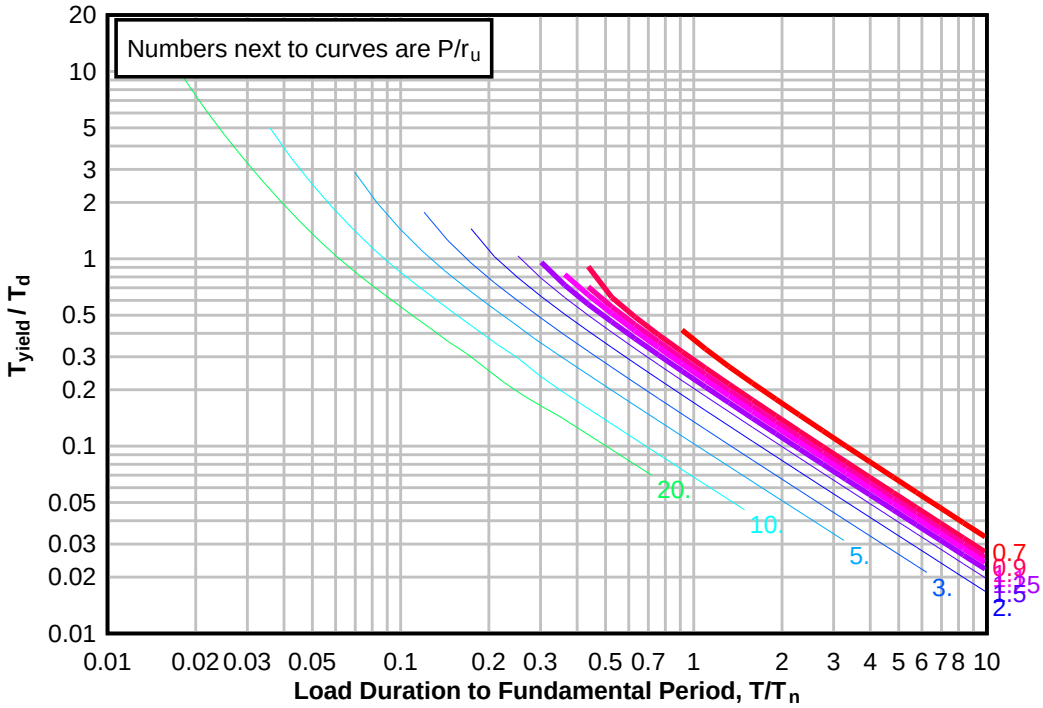


Figure 3-84(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.010, C_2 = 3.0)

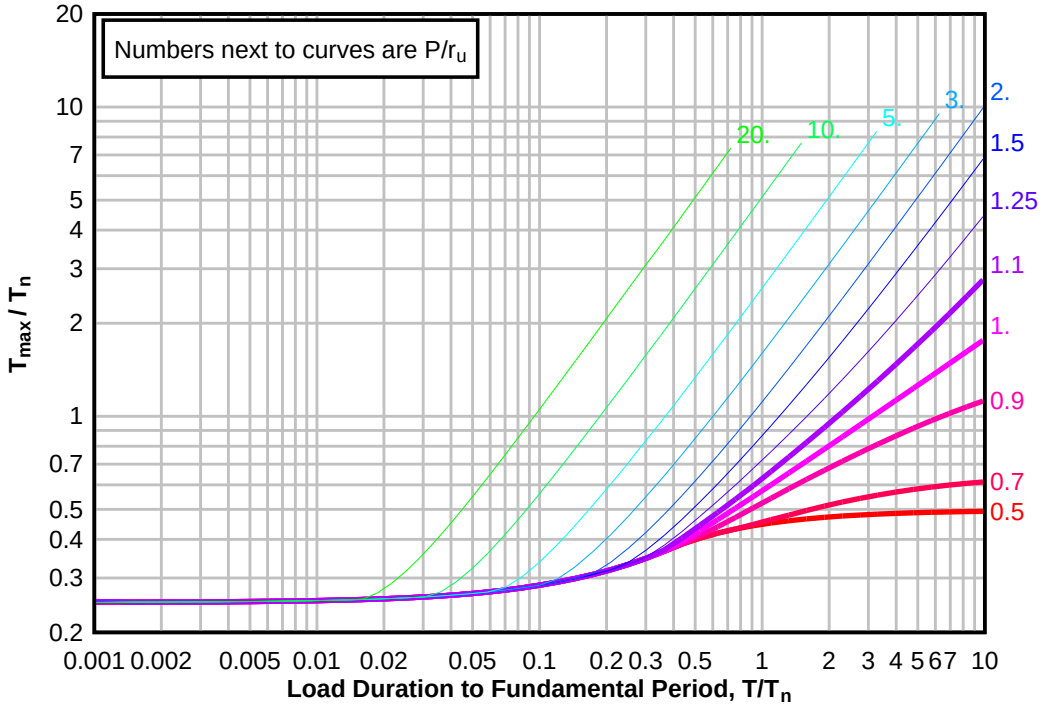


Figure 3-84(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.010, C2 = 3.0)

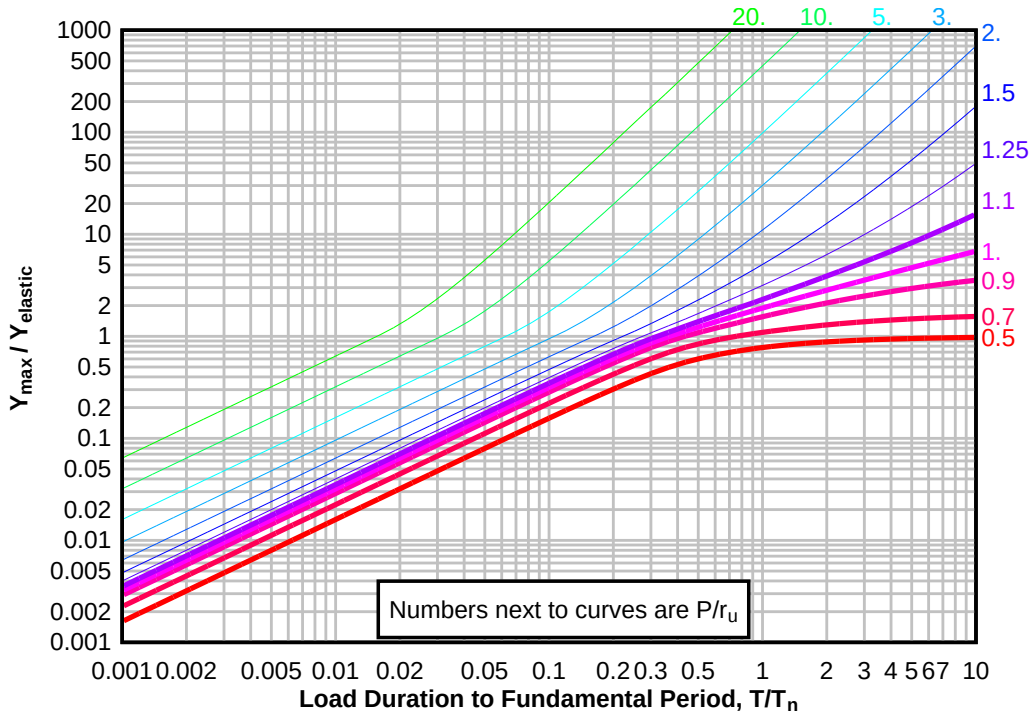


Figure 3-84(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.010, C2 = 3.0)

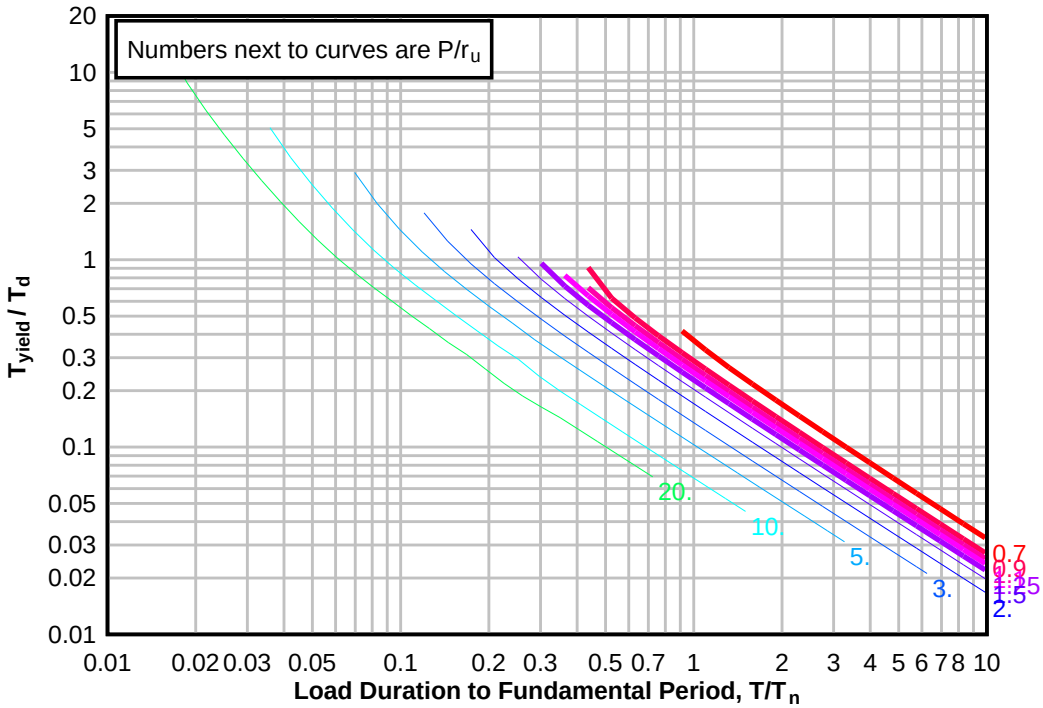


Figure 3-85(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.750, C_2 = 5.5)

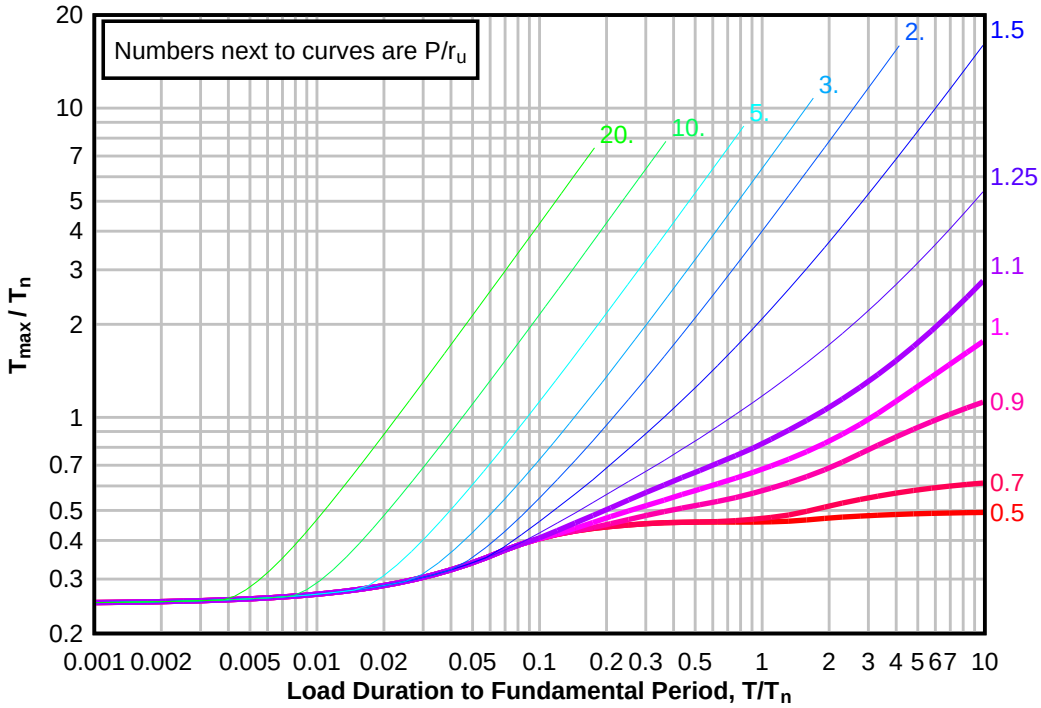


Figure 3-85(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.750, C2 = 5.5)

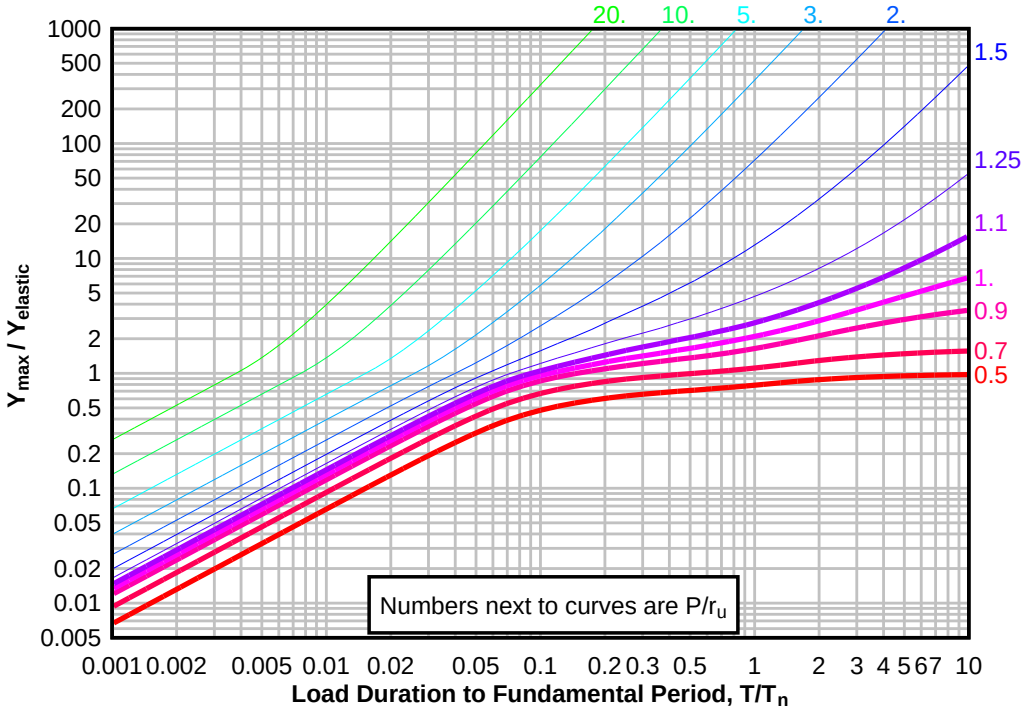


Figure 3-85(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.750, C2 = 5.5)

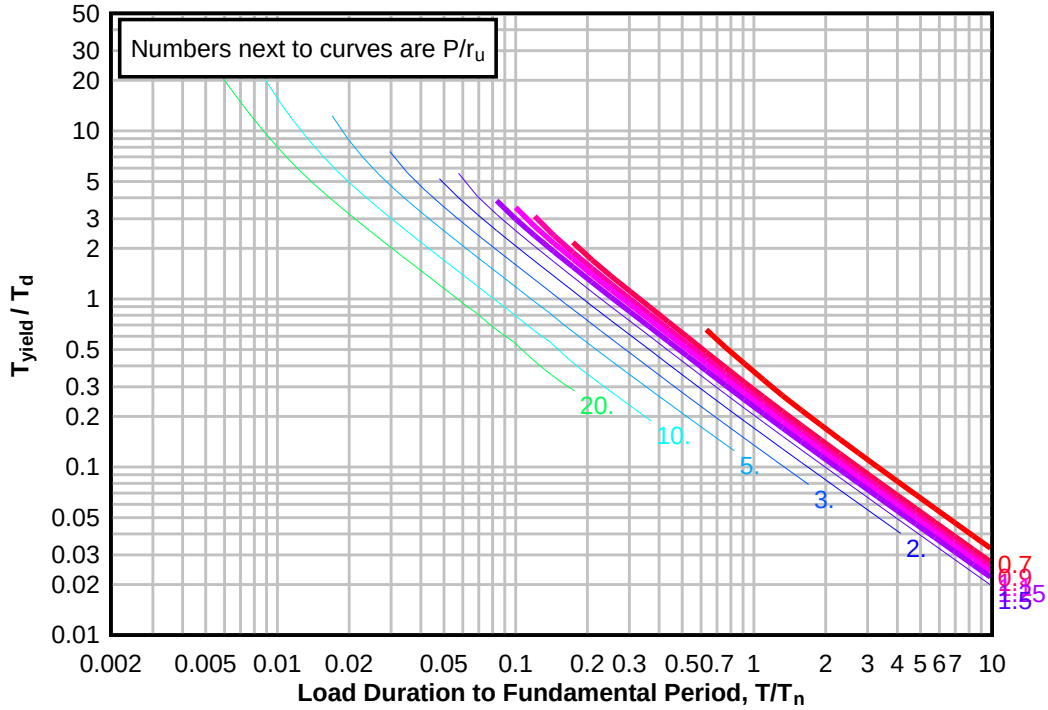


Figure 3-86(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.562, C_2 = 5.5)

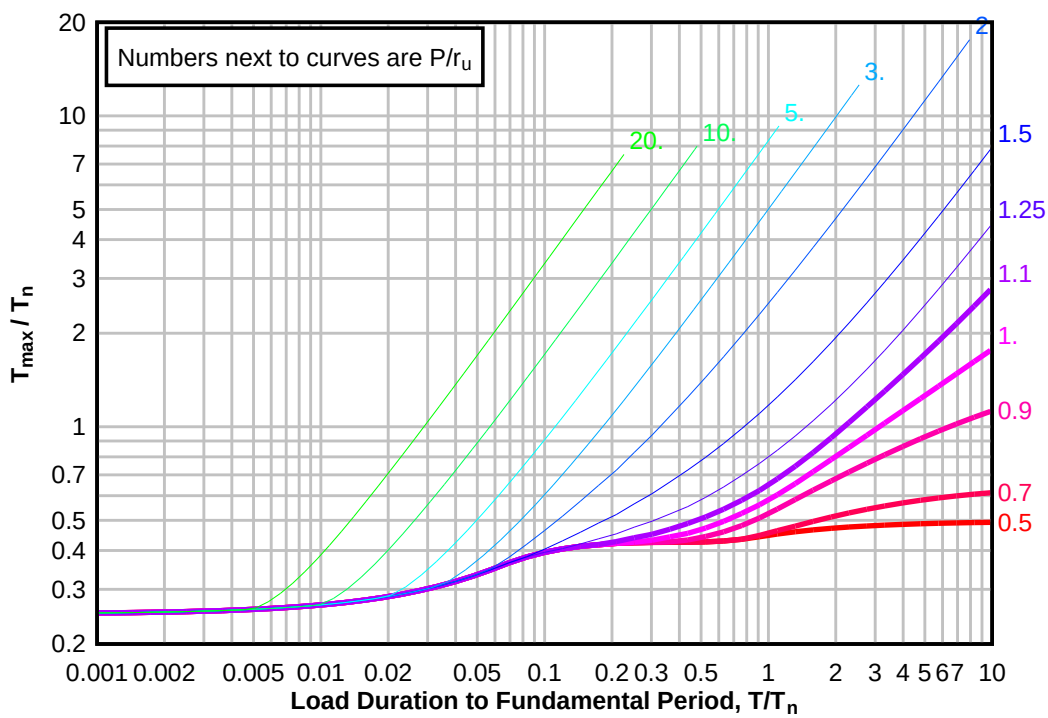


Figure 3-86(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.562, C2 = 5.5)

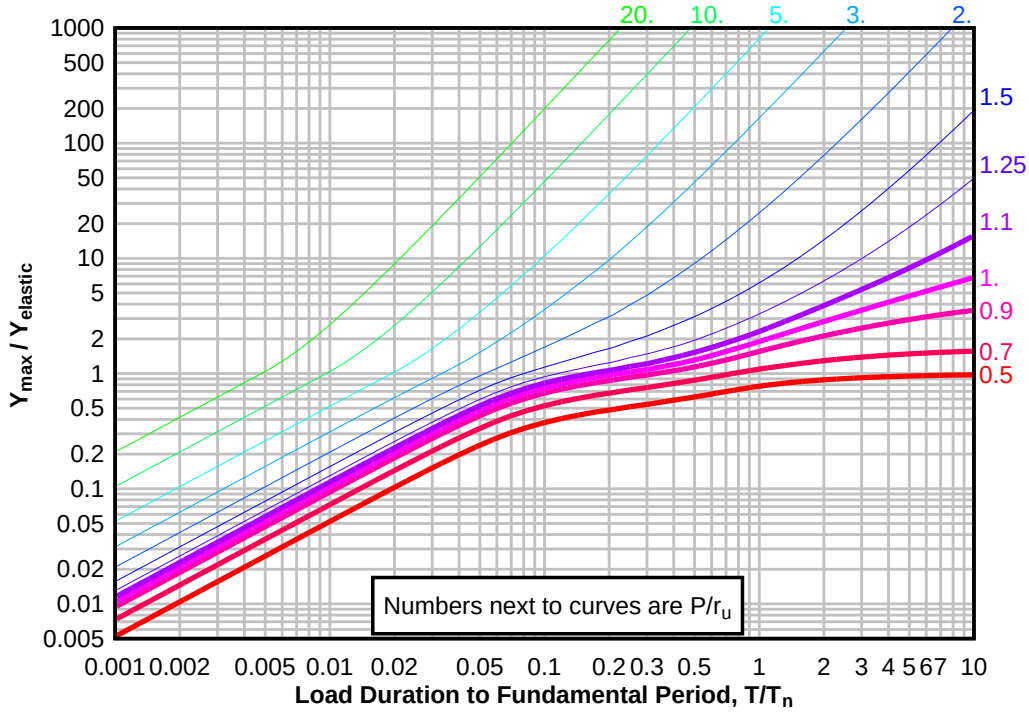


Figure 3-86(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.562, C2 = 5.5)

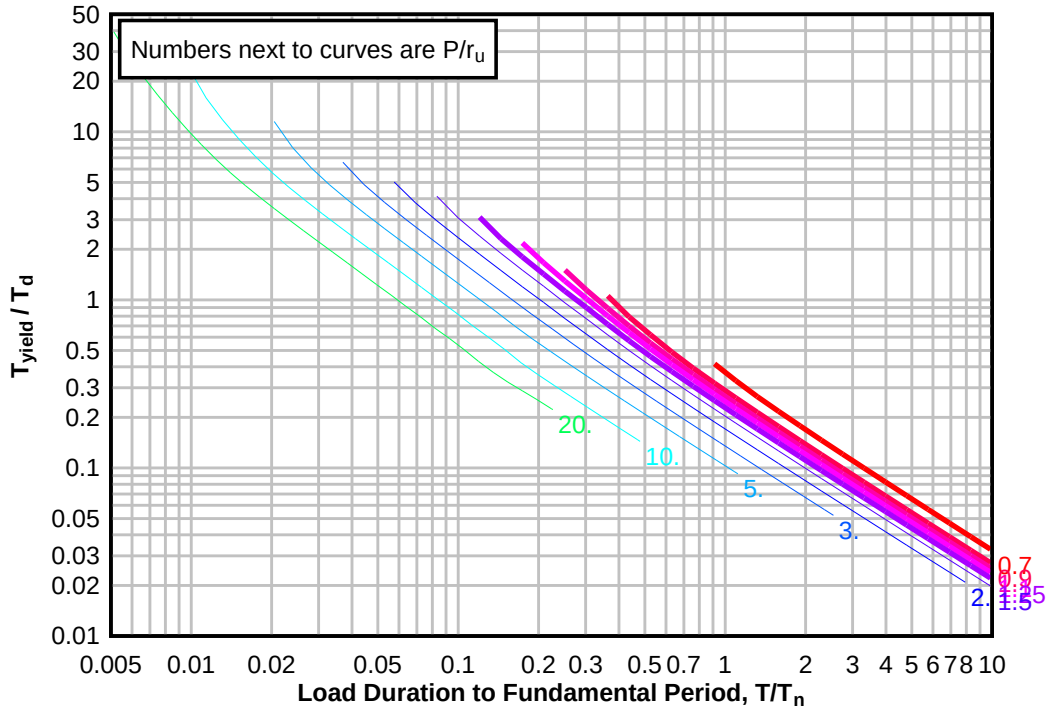


Figure 3-87(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.422, C_2 = 5.5)

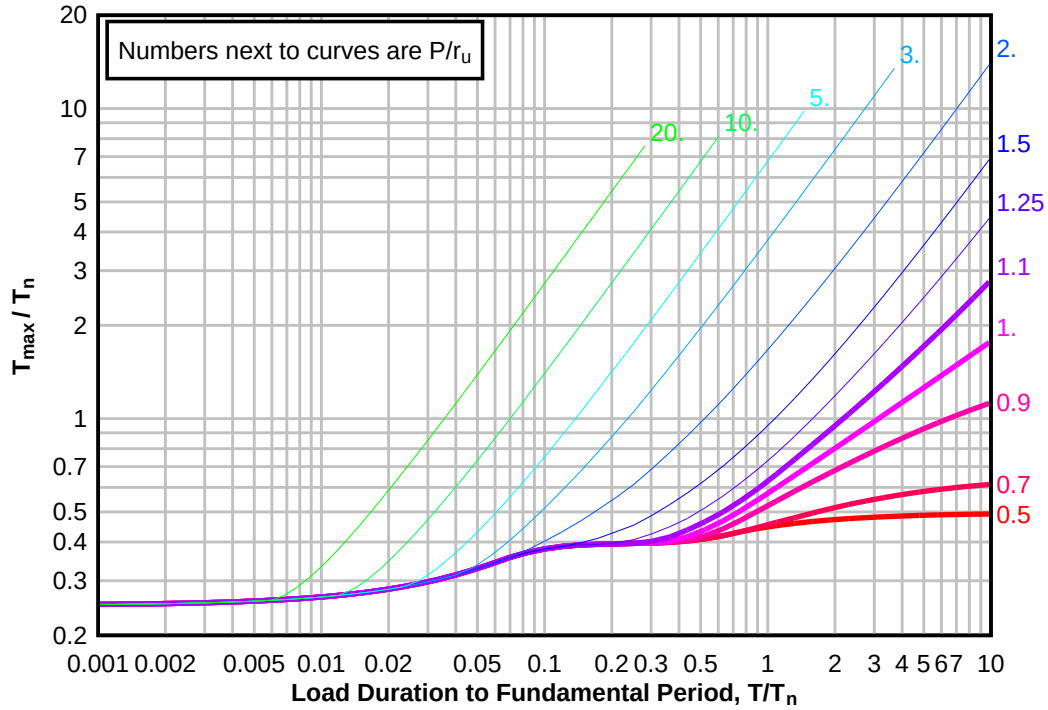


Figure 3-87(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.422, C2 = 5.5)

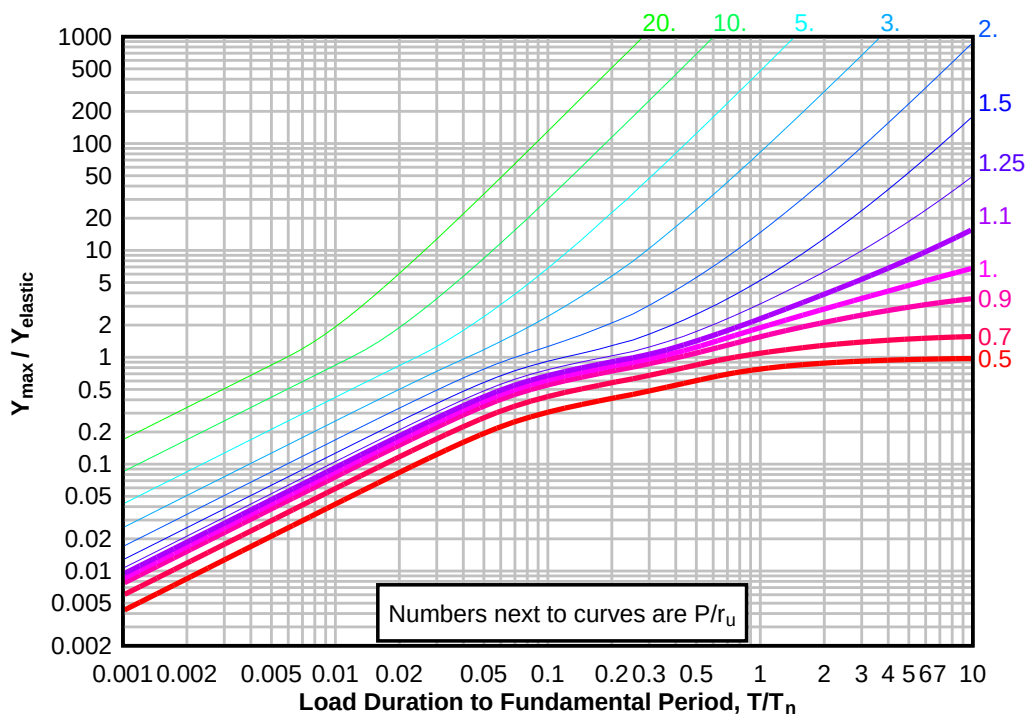


Figure 3-87(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.422, C2 = 5.5)

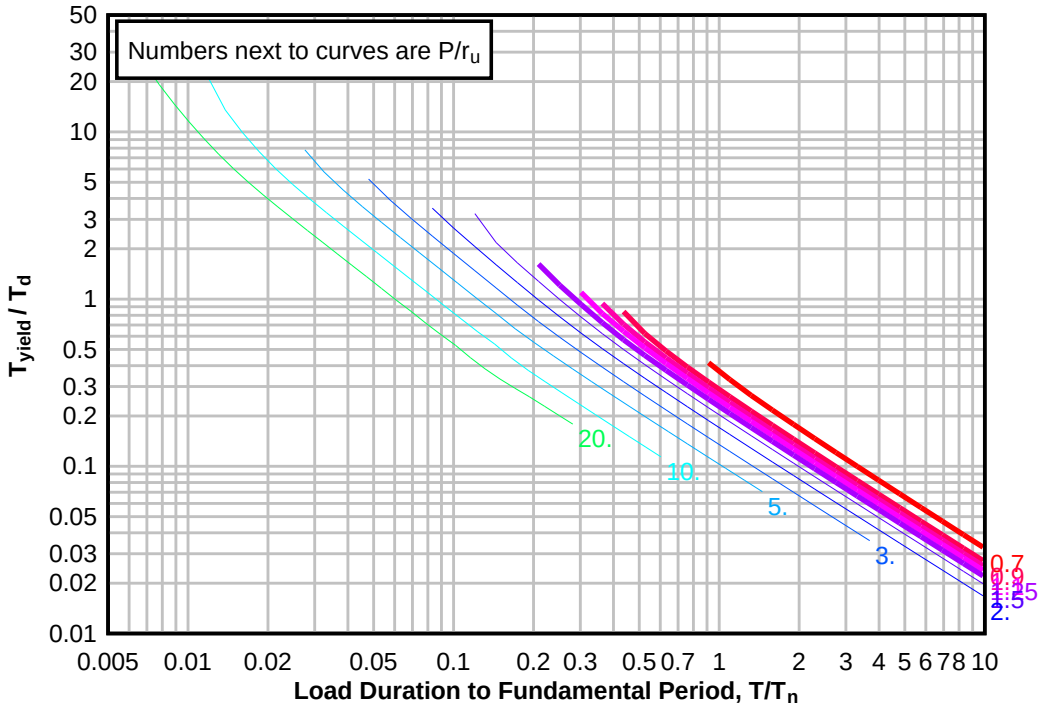


Figure 3-88(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.316, C_2 = 5.5)

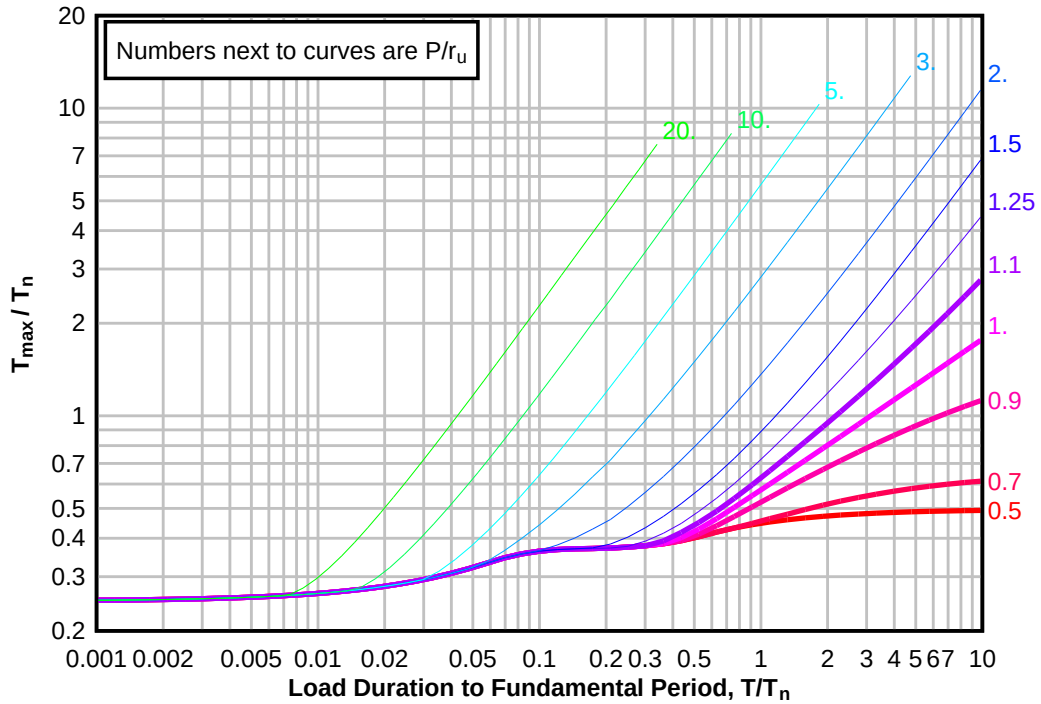


Figure 3-88(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.316, C2 = 5.5)

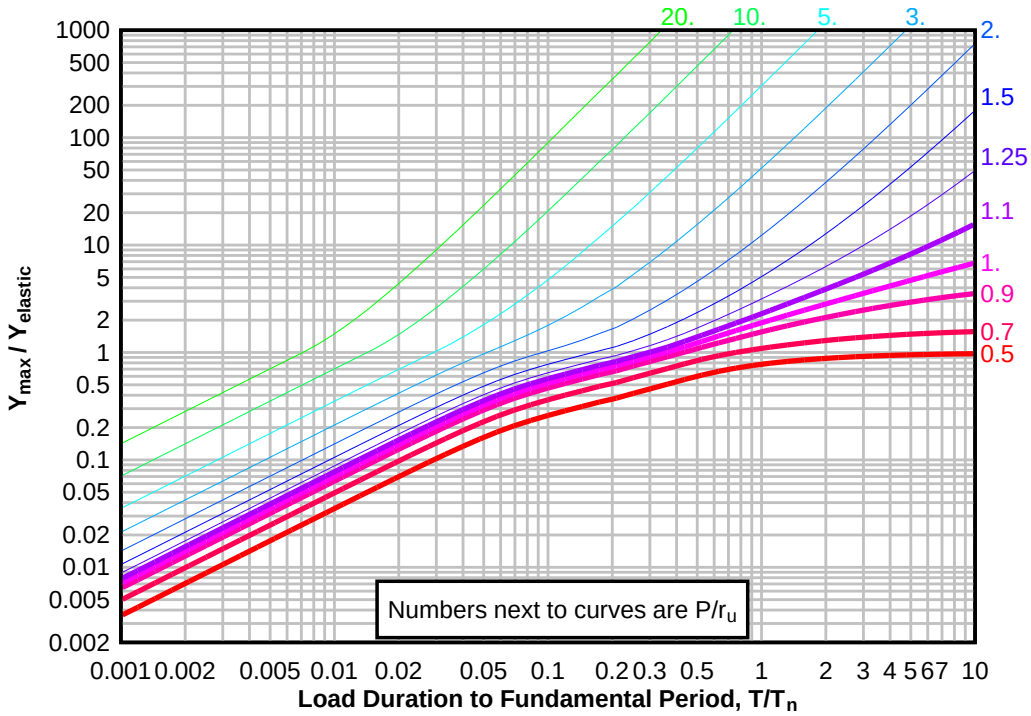


Figure 3-88(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.316, C2 = 5.5)

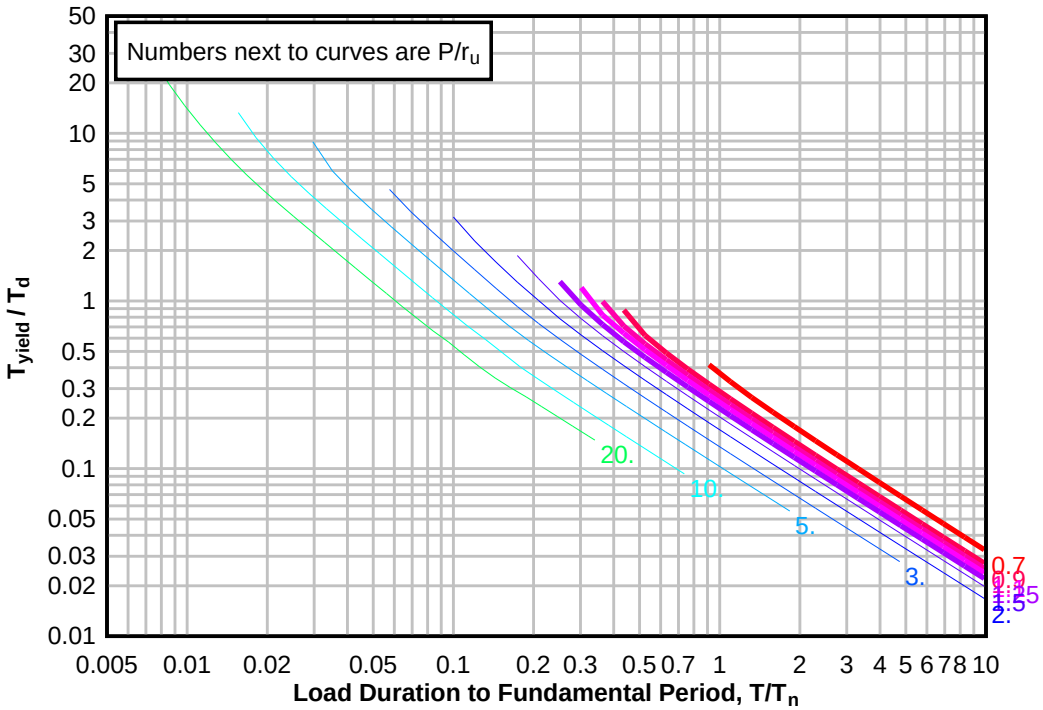


Figure 3-89(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.237, C_2 = 5.5)

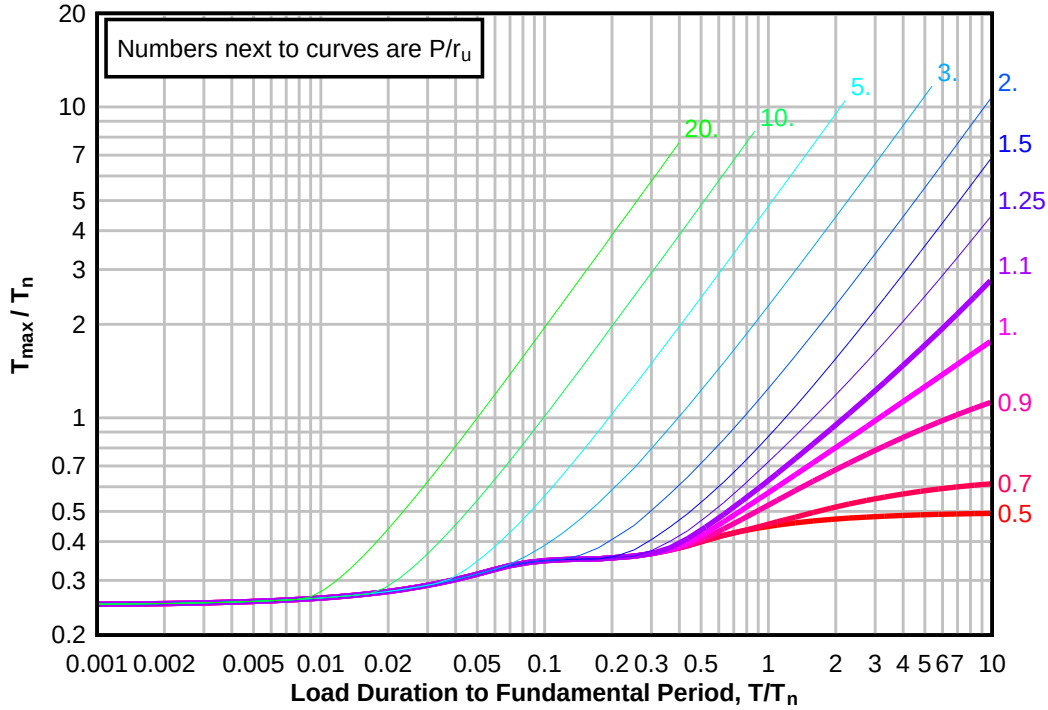


Figure 3-89(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.237, C2 = 5.5)

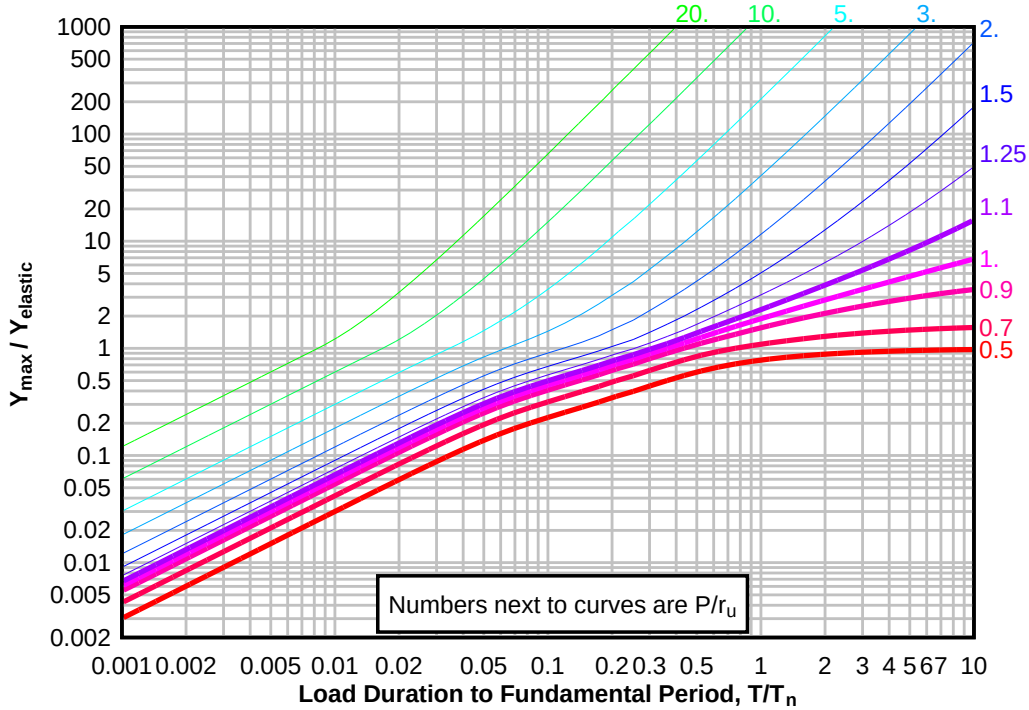


Figure 3-89(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.237, C2 = 5.5)

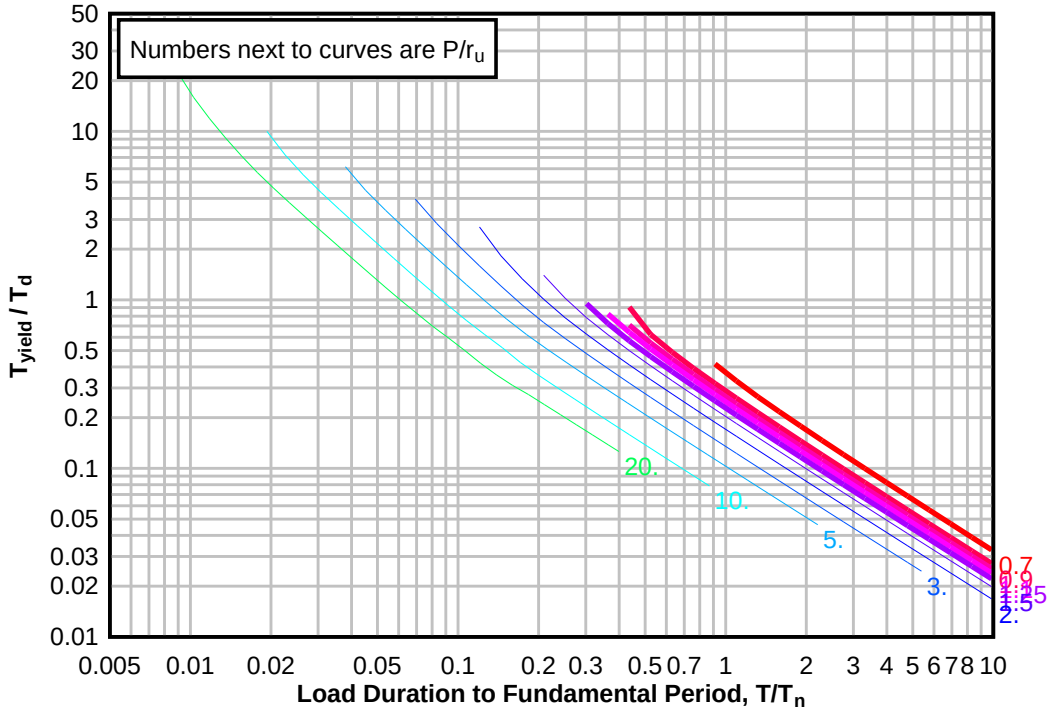


Figure 3-90(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.178, C_2 = 5.5)

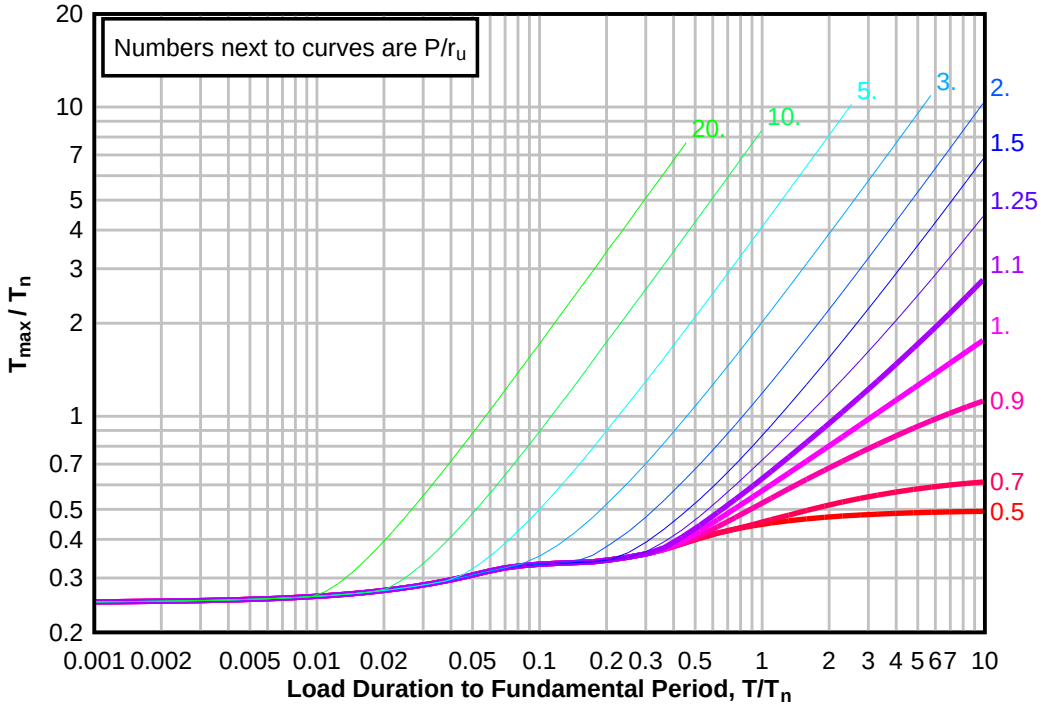


Figure 3-90(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.178, C2 = 5.5)

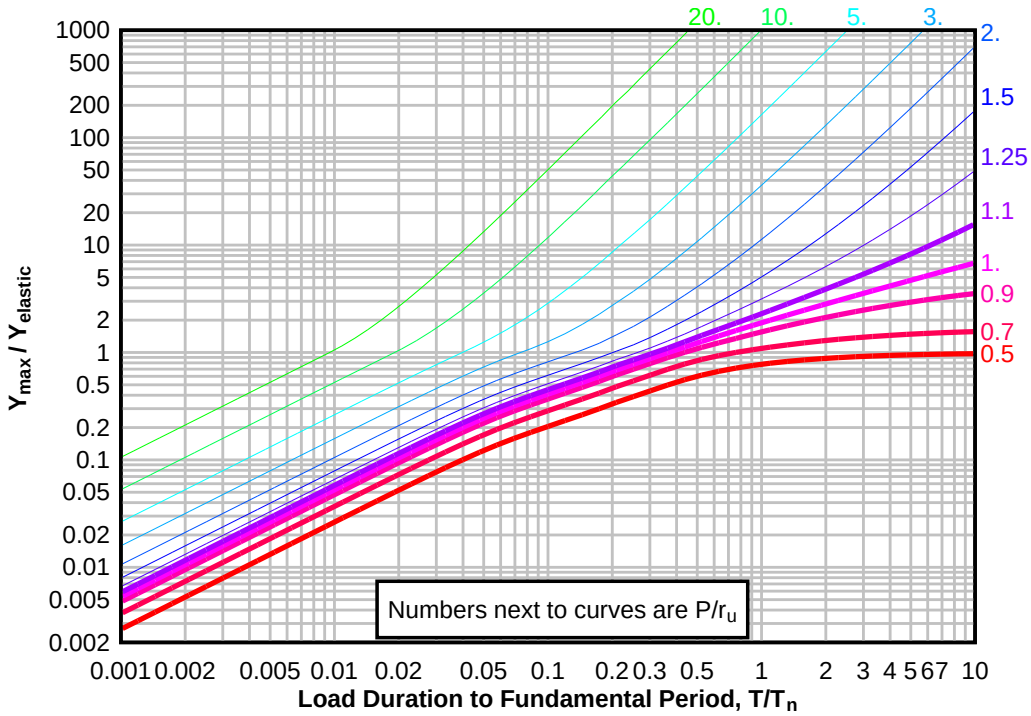


Figure 3-90(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.178, C2 = 5.5)

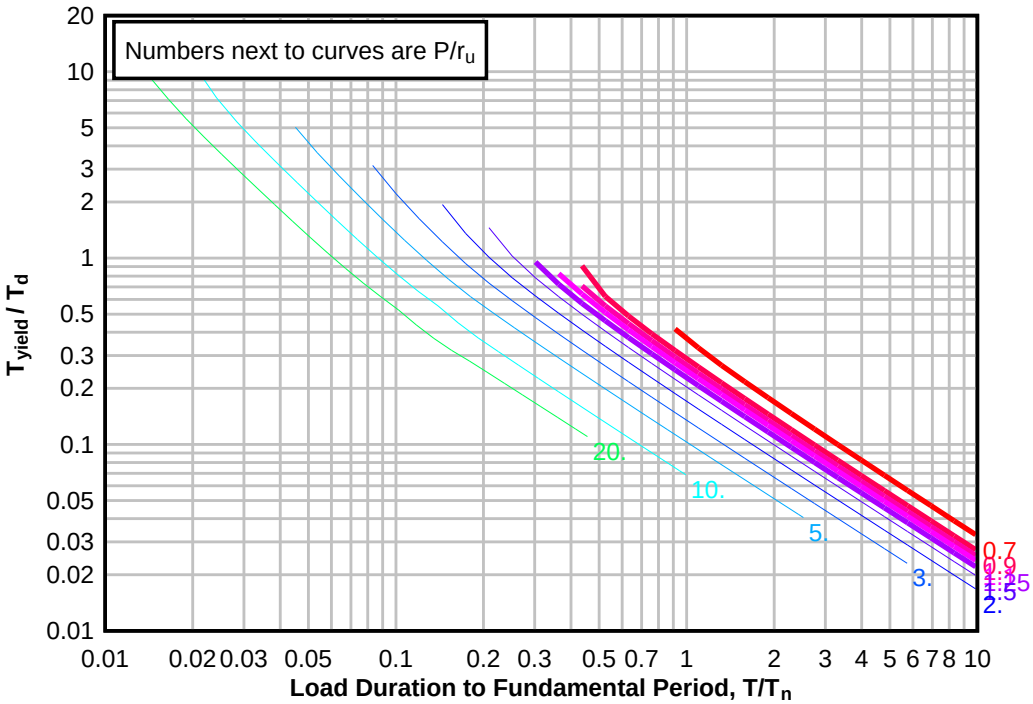


Figure 3-91(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.133, C_2 = 5.5)

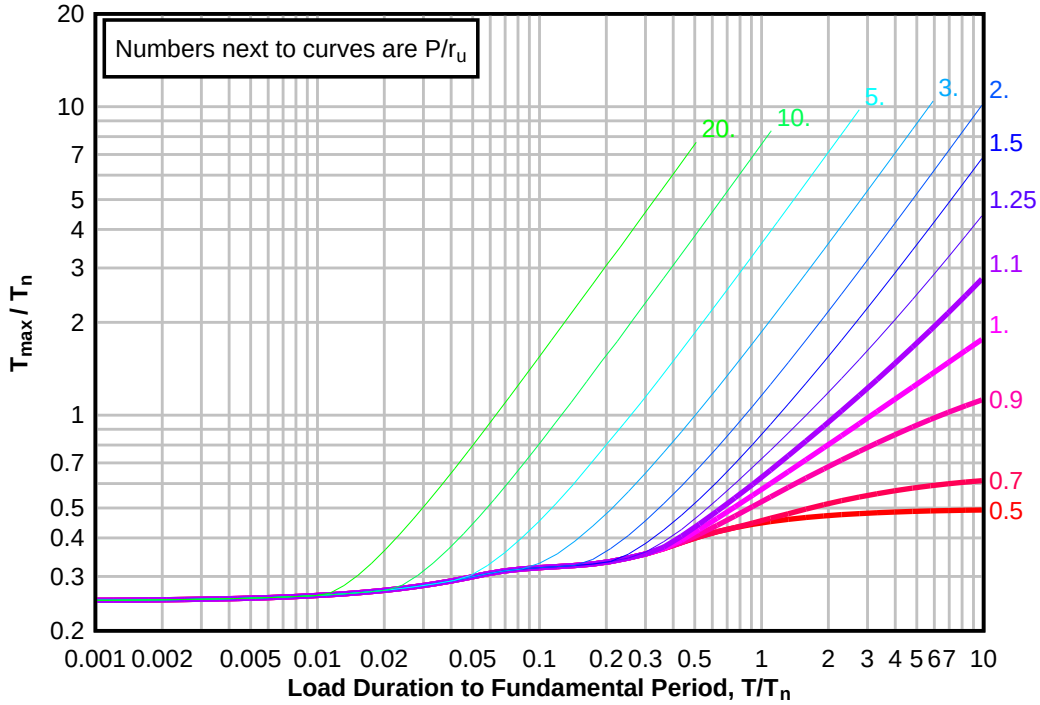


Figure 3-91(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.133, C2 = 5.5)

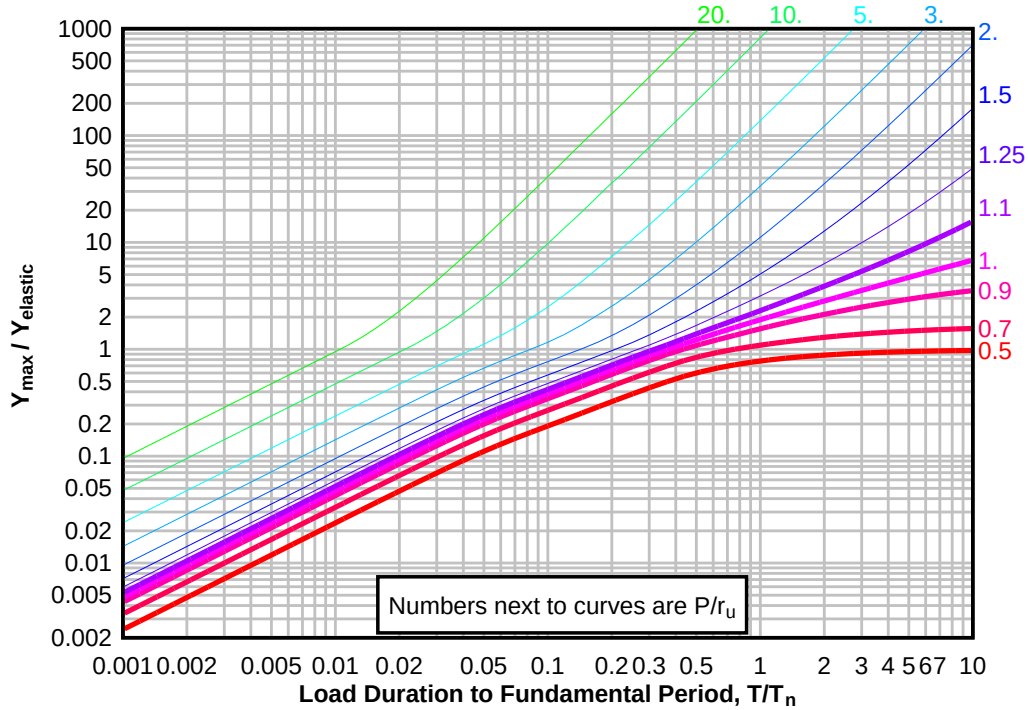


Figure 3-91(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.133, C2 = 5.5)

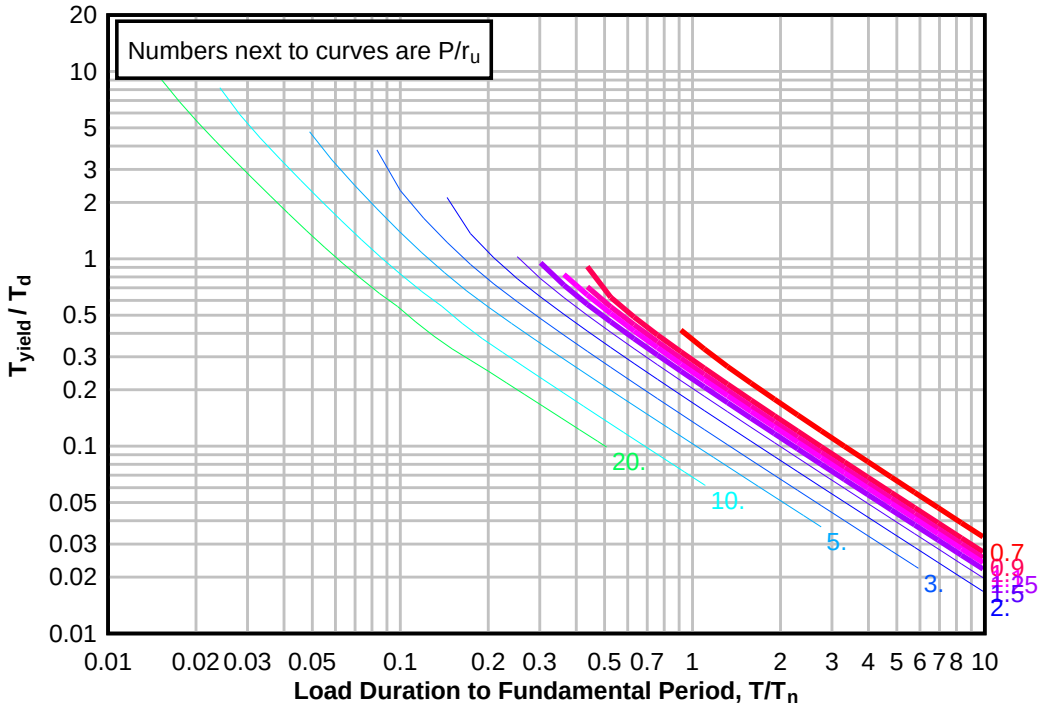


Figure 3-92(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.100, C_2 = 5.5)

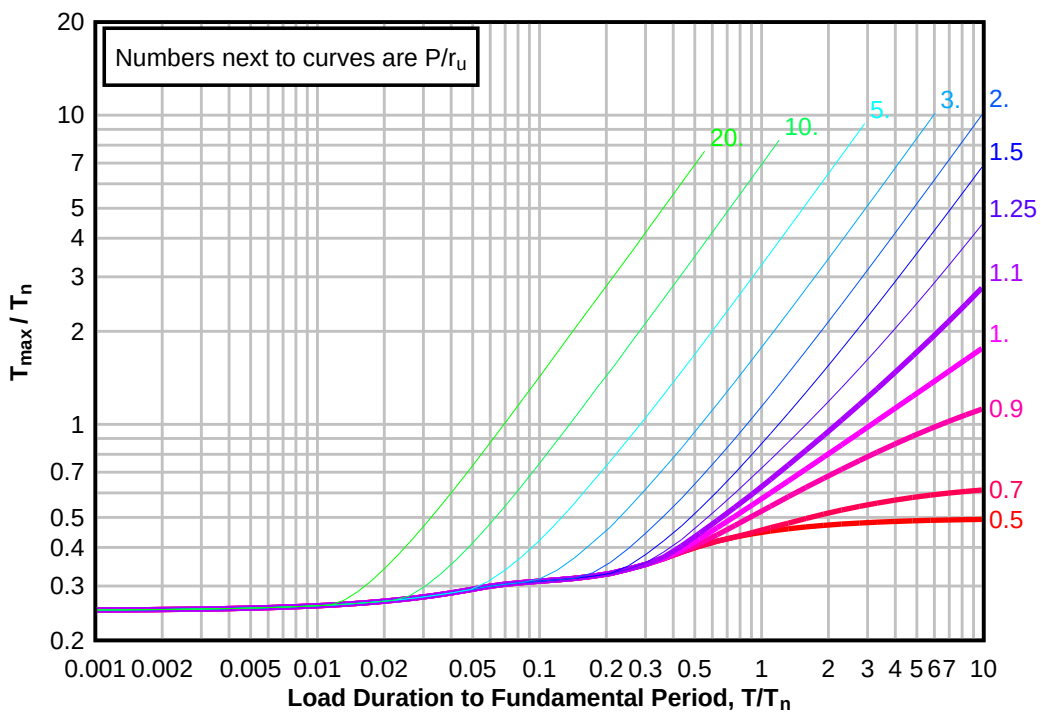


Figure 3-92(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.100, C2 = 5.5)

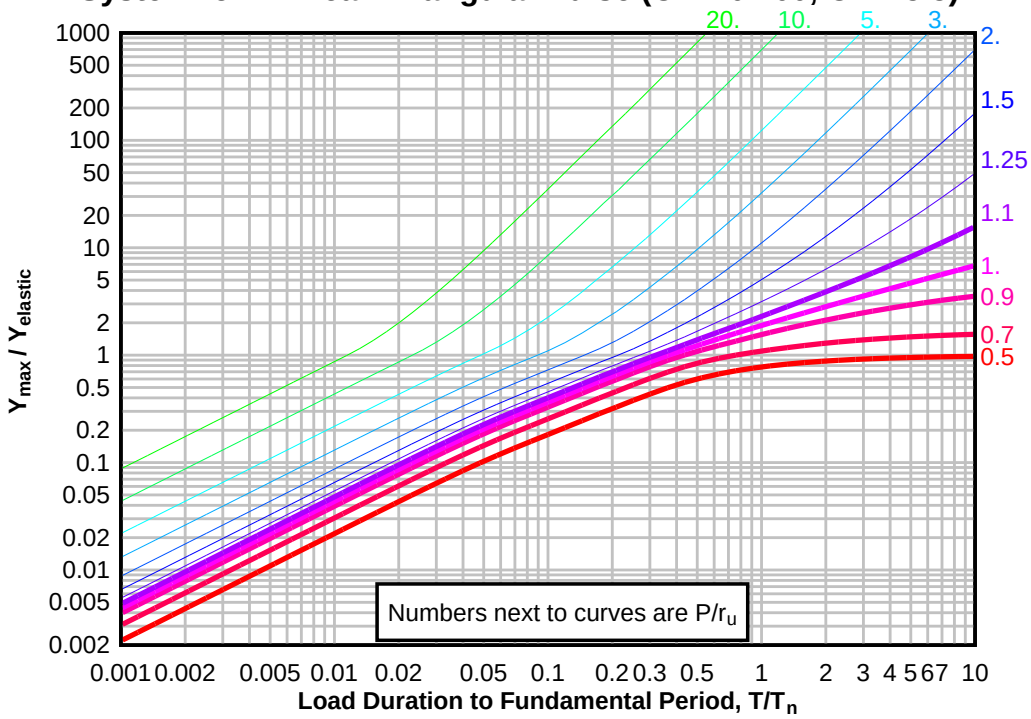


Figure 3-92(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.100, C2 = 5.5)

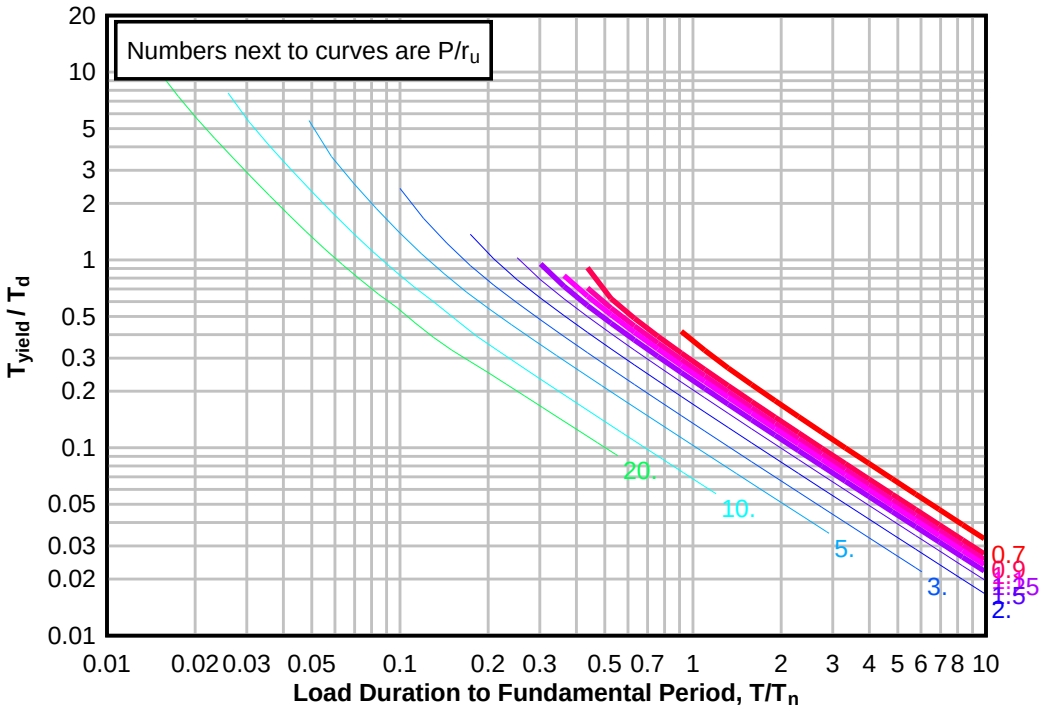


Figure 3-93(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.068, C_2 = 5.5)

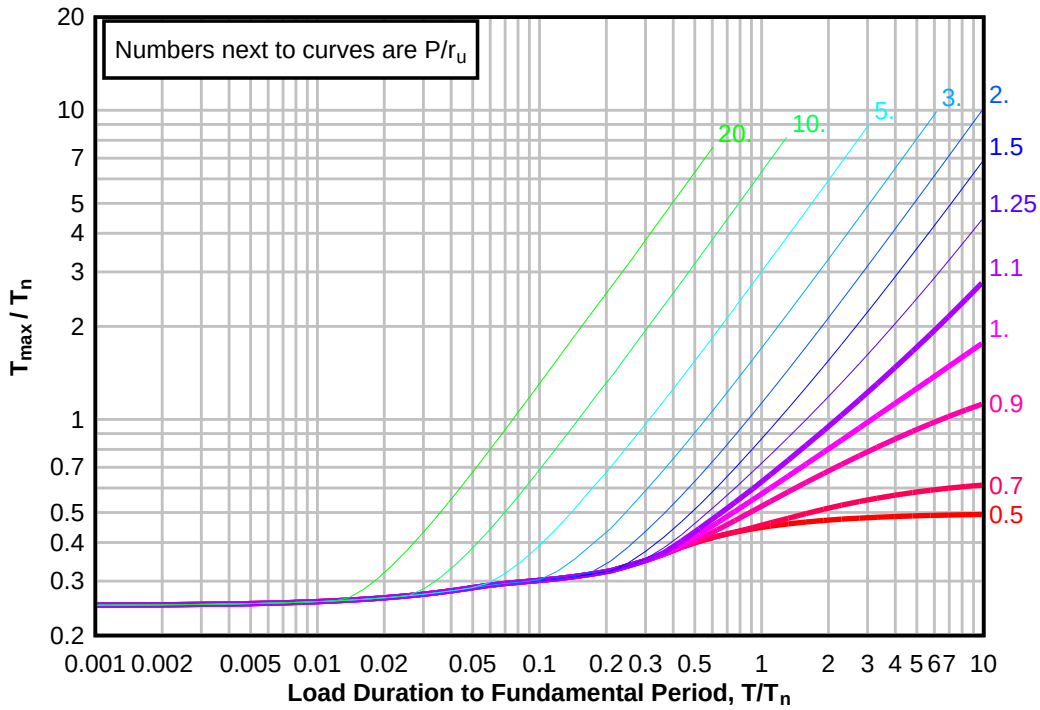


Figure 3-93(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.068, C2 = 5.5)

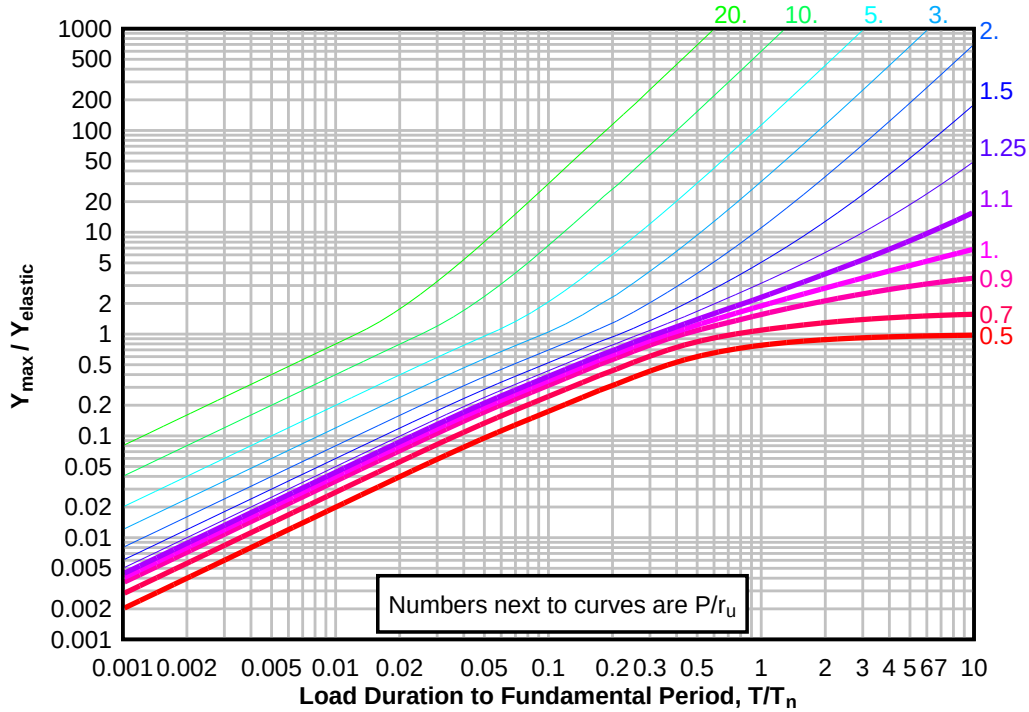


Figure 3-93(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.068, C2 = 5.5)

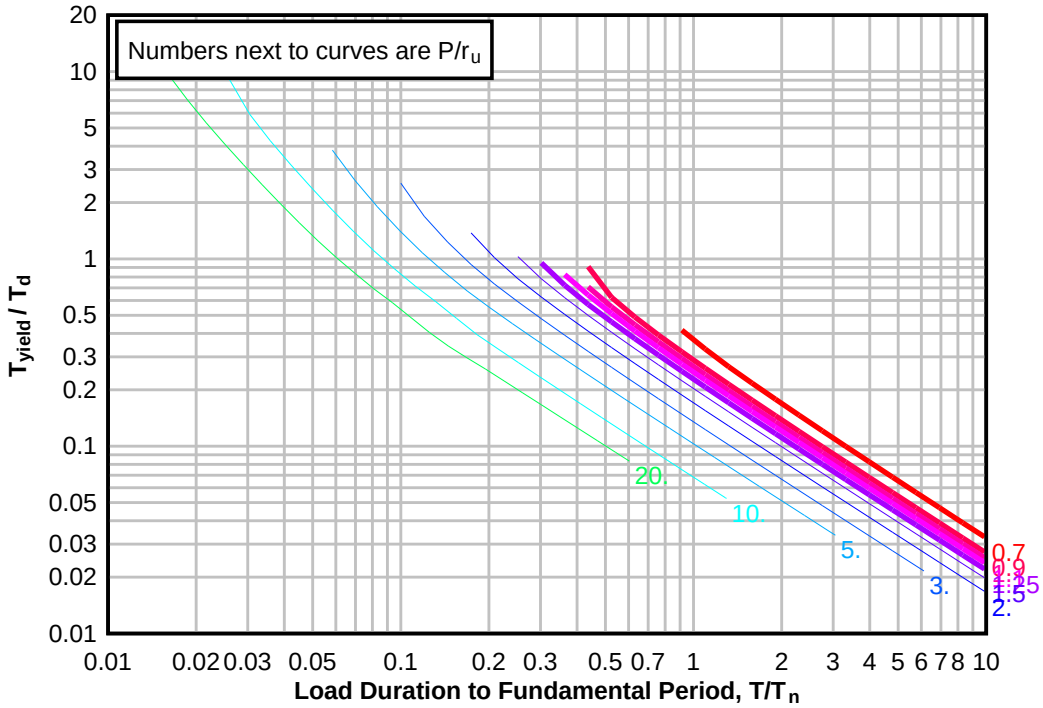


Figure 3-94(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.046, C_2 = 5.5)

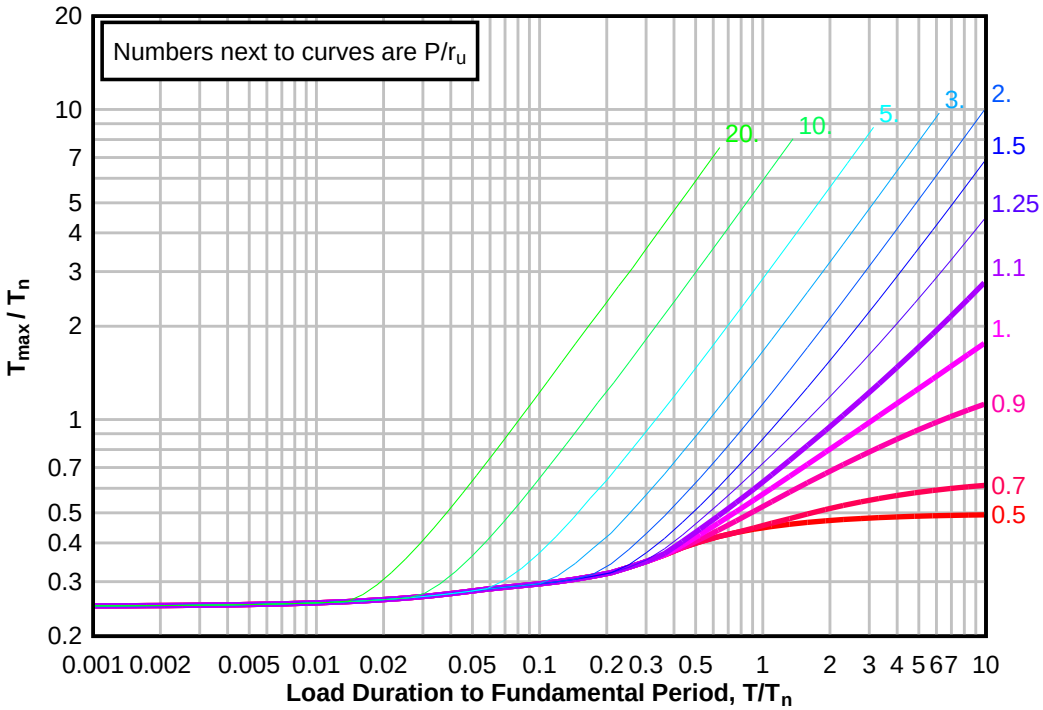


Figure 3-94(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.046, C2 = 5.5)

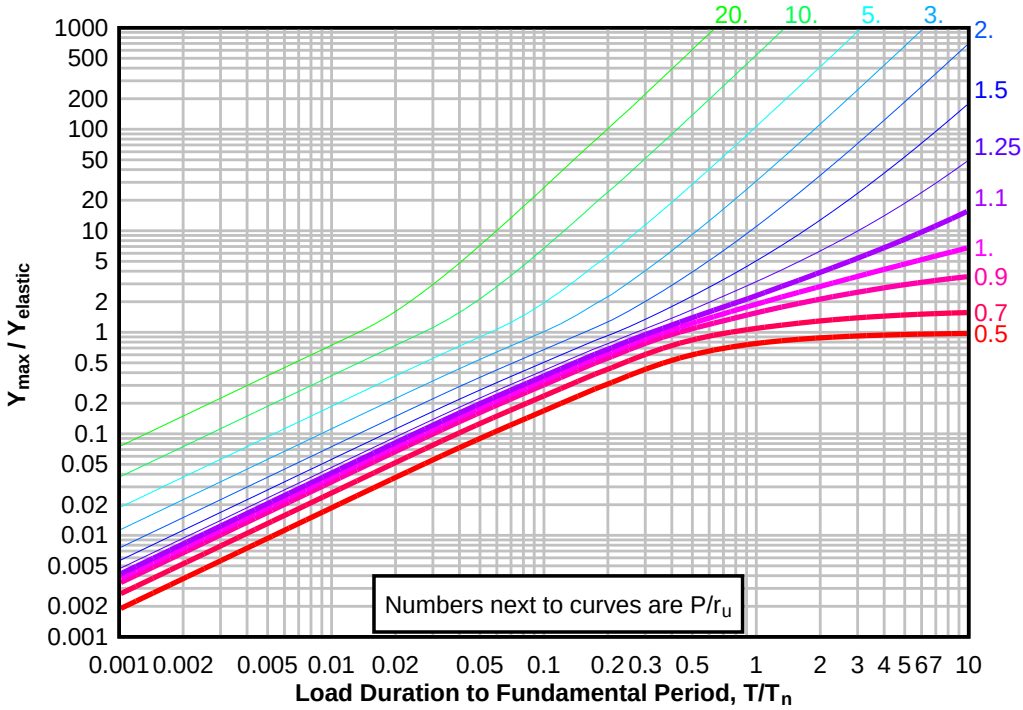


Figure 3-94(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.046, C2 = 5.5)

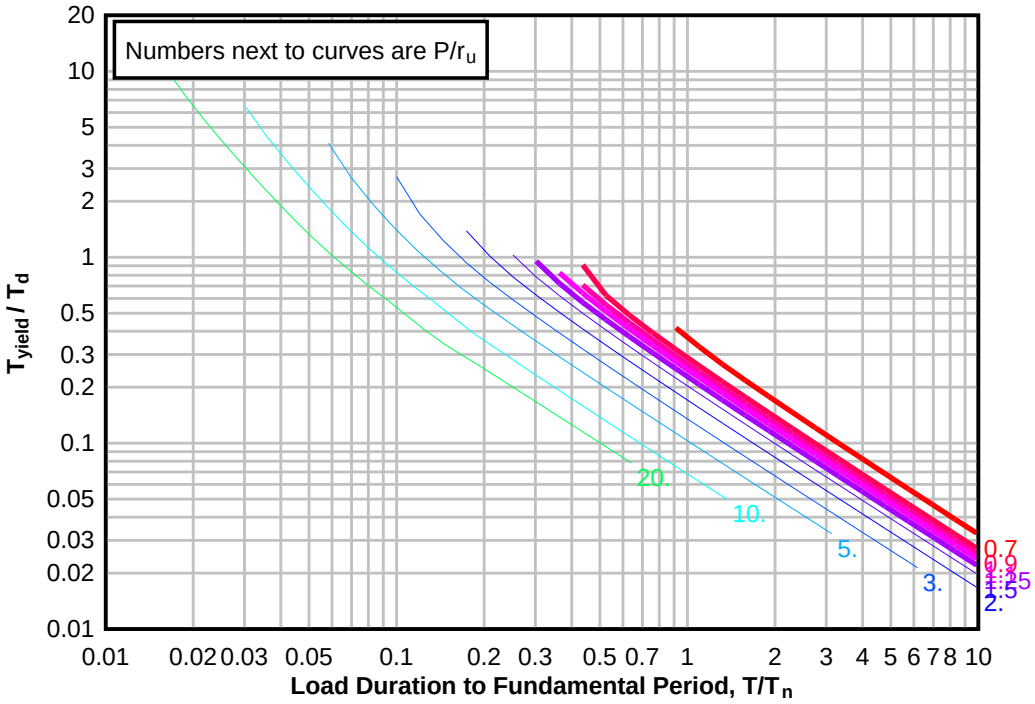


Figure 3-95(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.032, C_2 = 5.5)

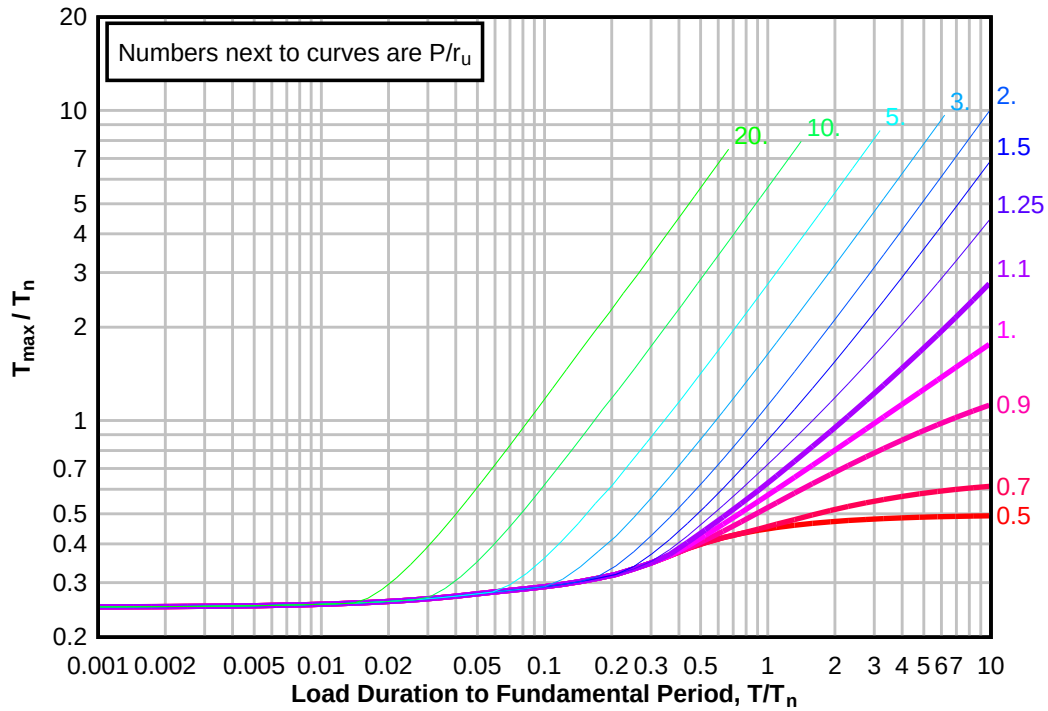


Figure 3-95(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.032, C2 = 5.5)

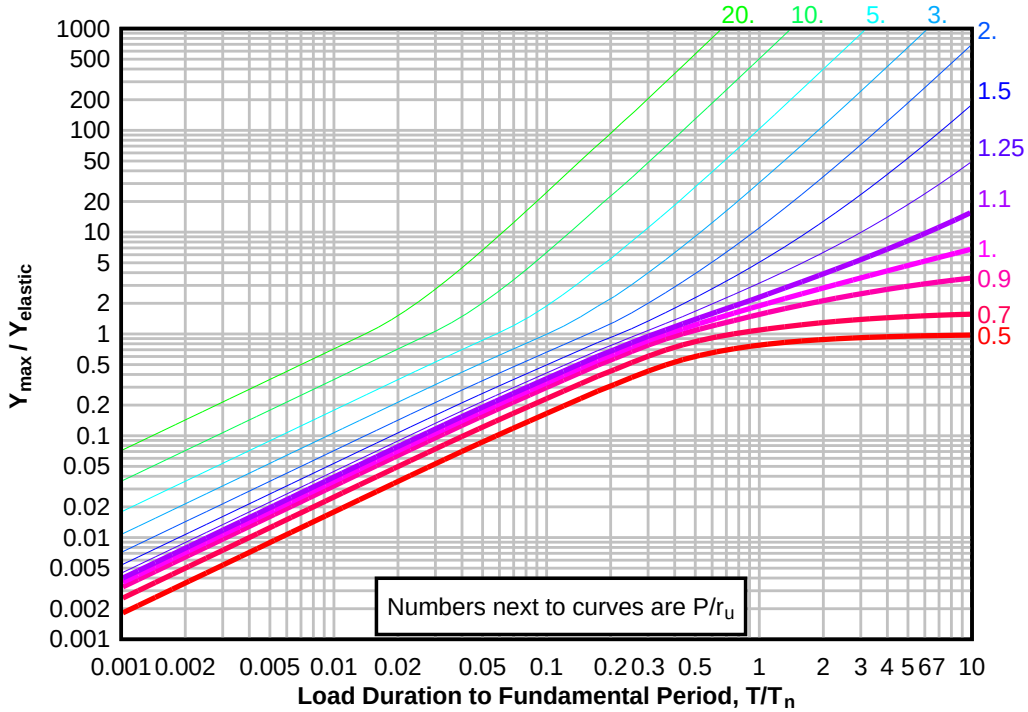


Figure 3-95(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.032, C2 = 5.5)

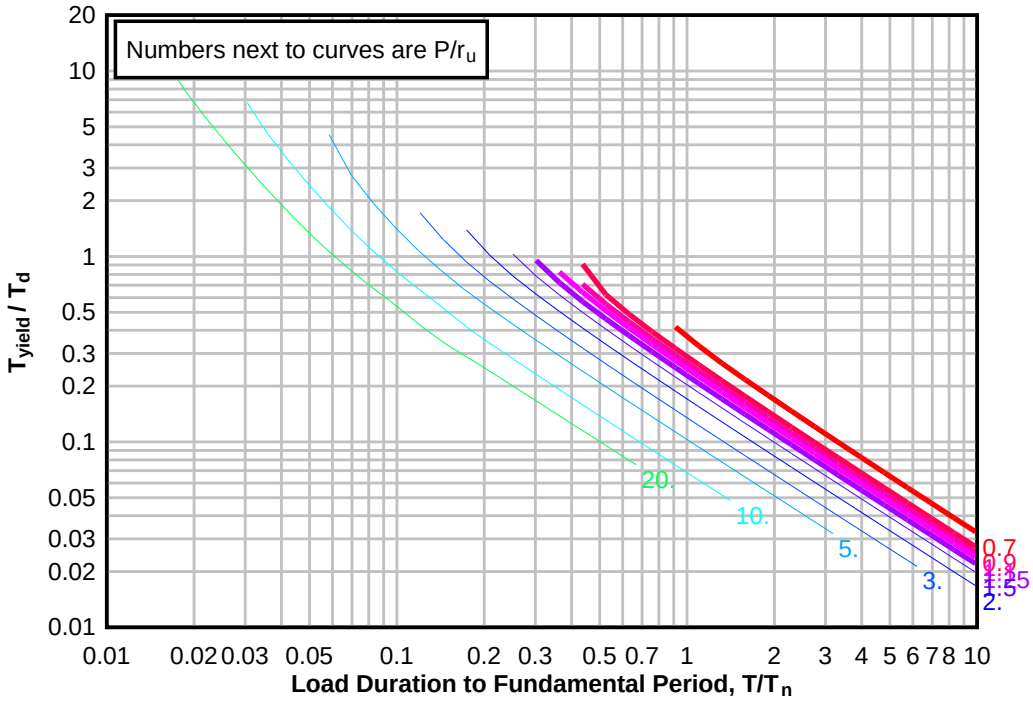


Figure 3-96(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.022, C_2 = 5.5)

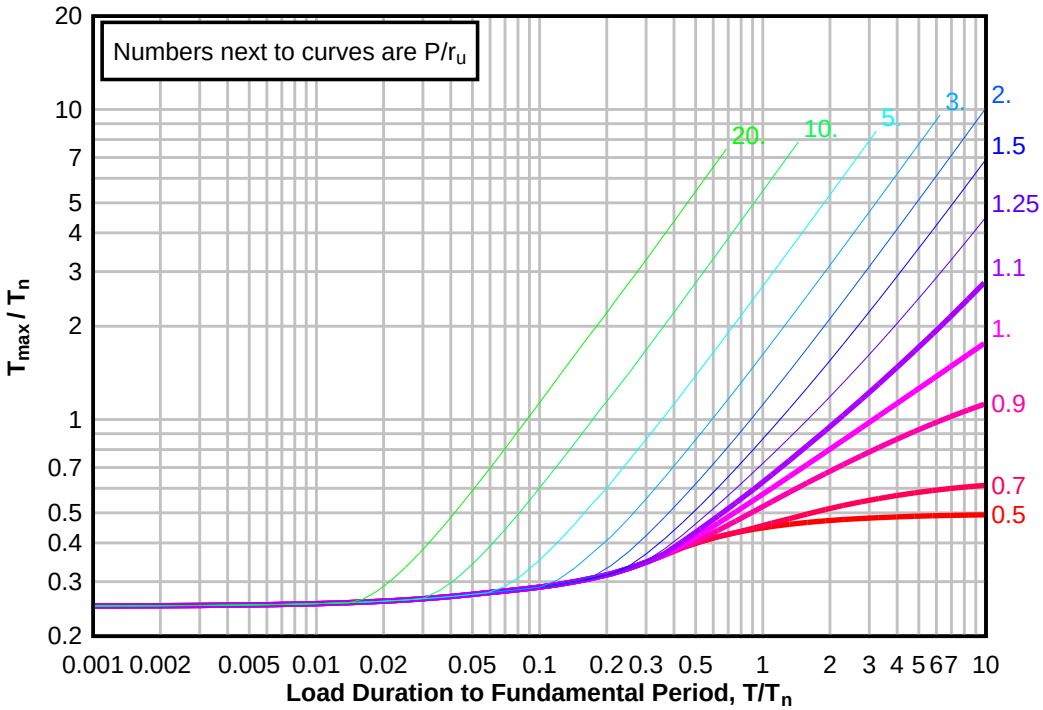


Figure 3-96(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.022, C2 = 5.5)

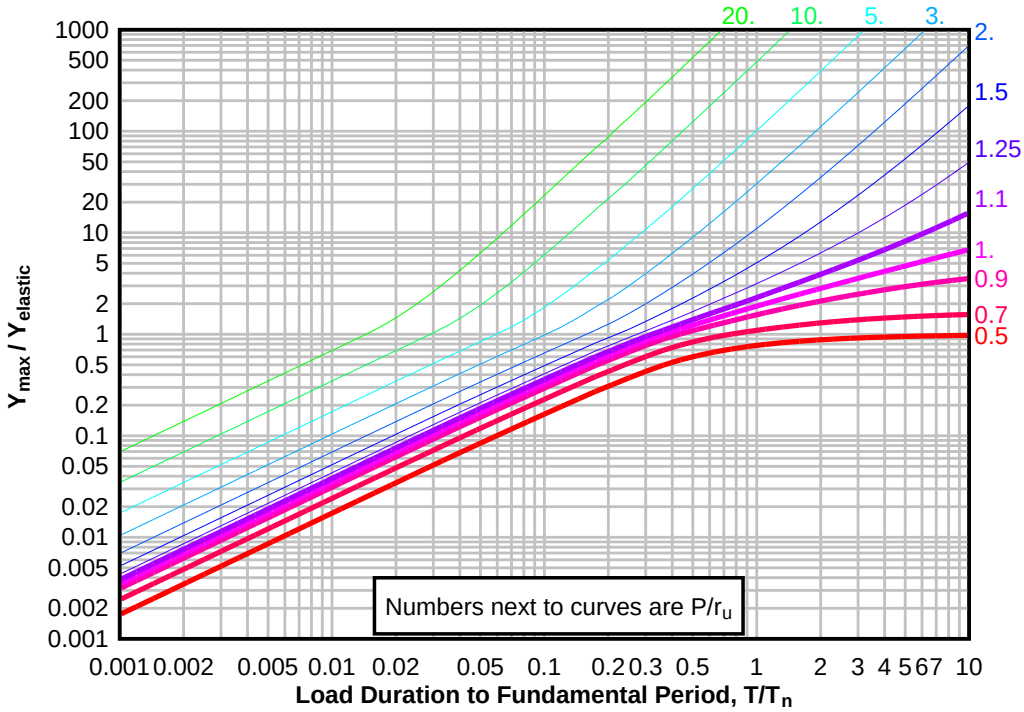


Figure 3-96(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.022, C2 = 5.5)

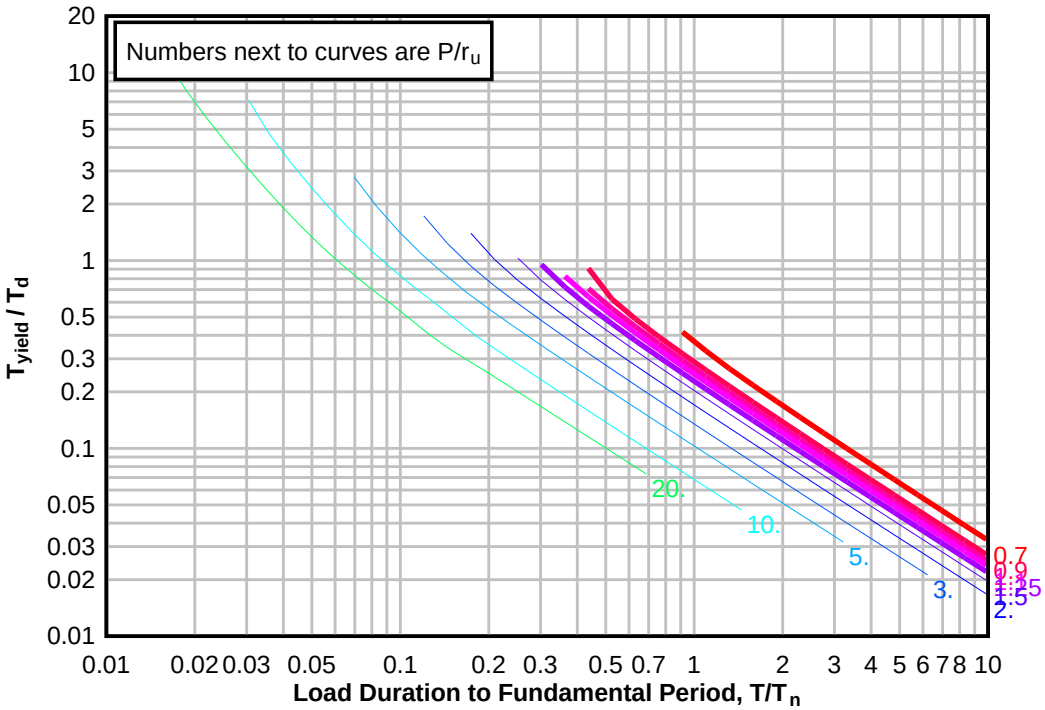


Figure 3-97(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.015, C_2 = 6)

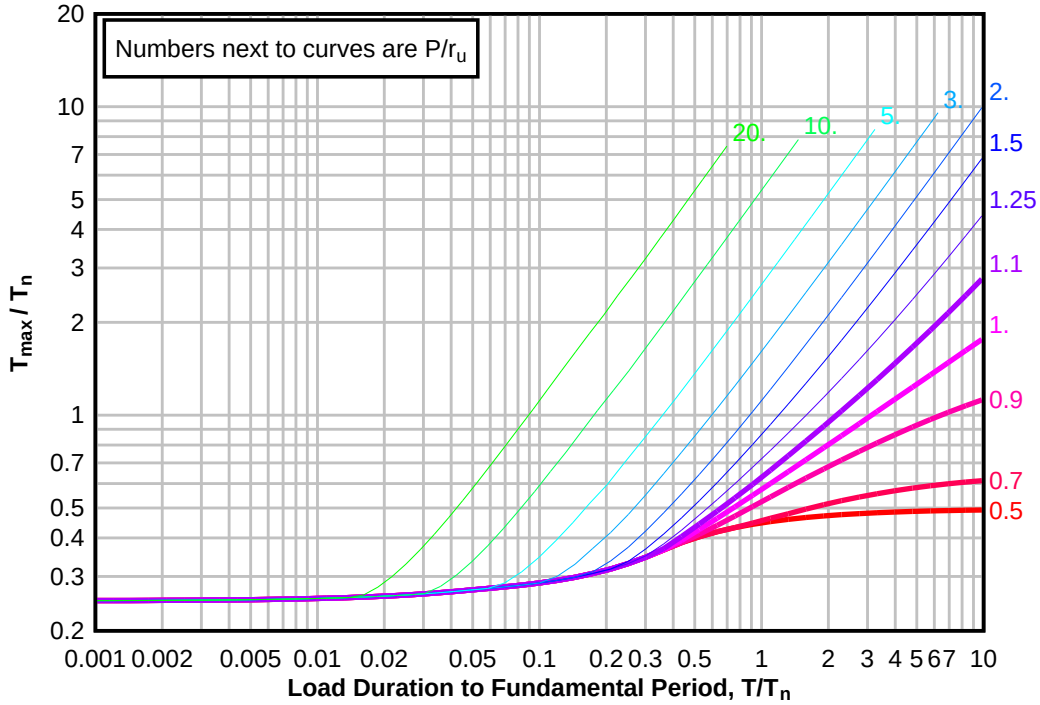


Figure 3-97(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.015, C2 = 6)

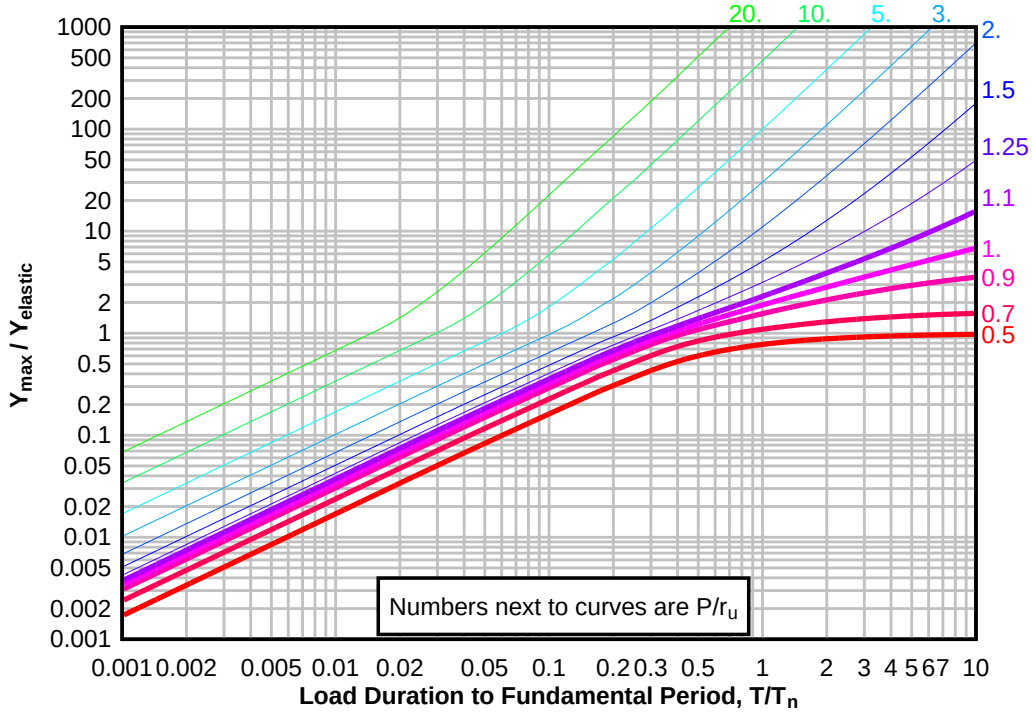


Figure 3-97(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.015, C2 = 6)

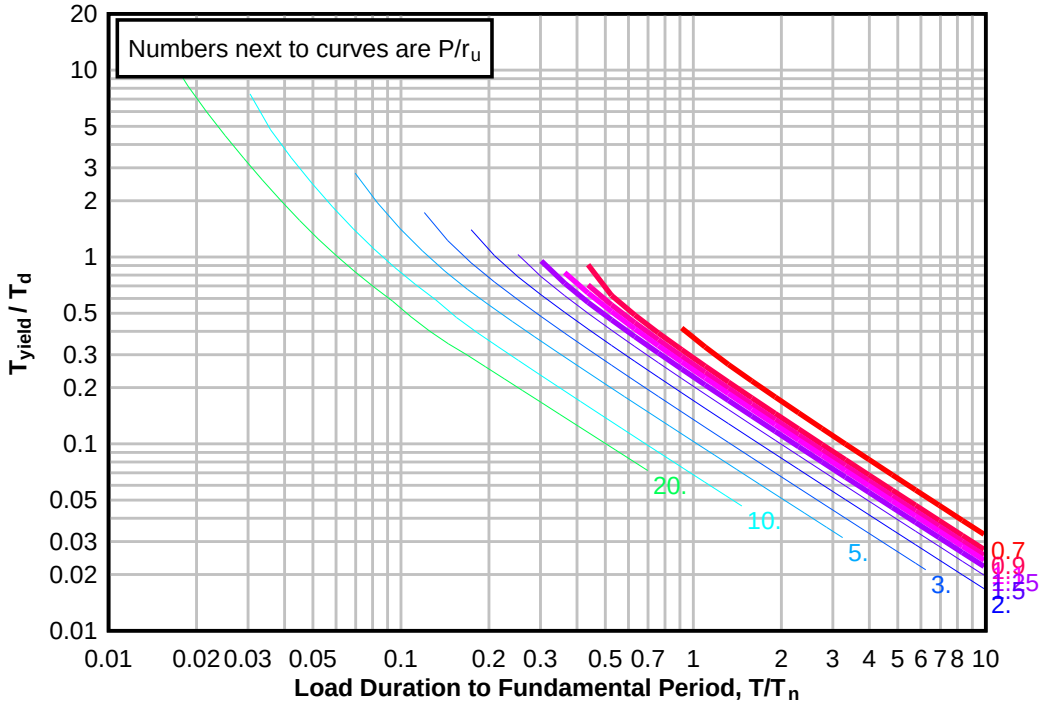


Figure 3-98(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.010, C_2 = 5.5)

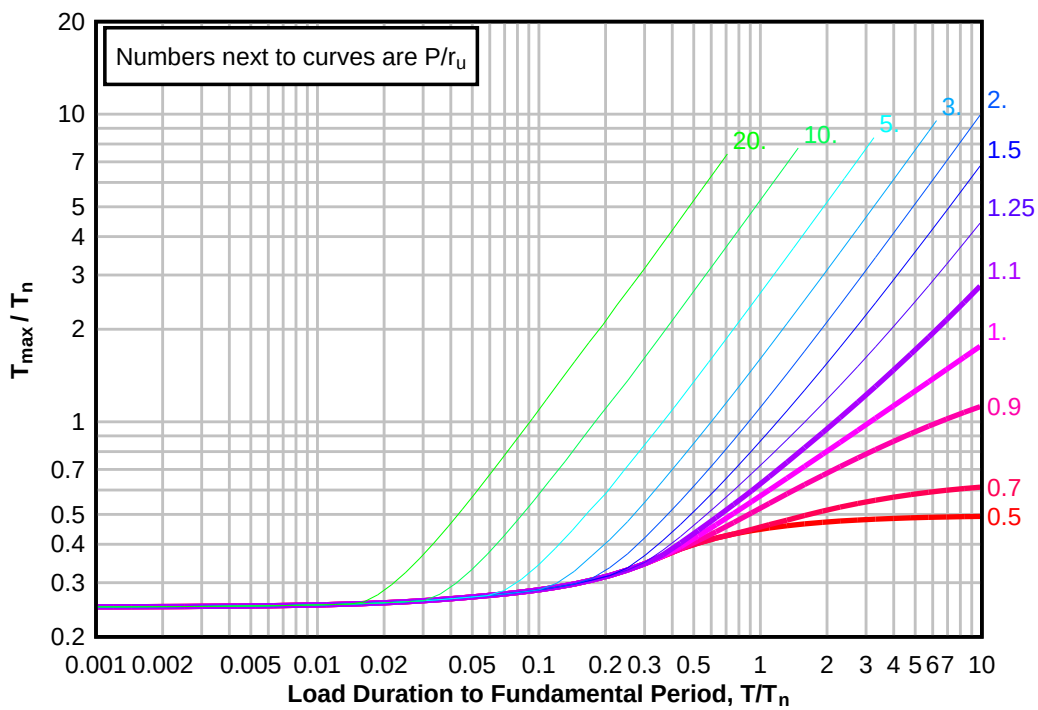


Figure 3-98(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.010, C2 = 5.5)

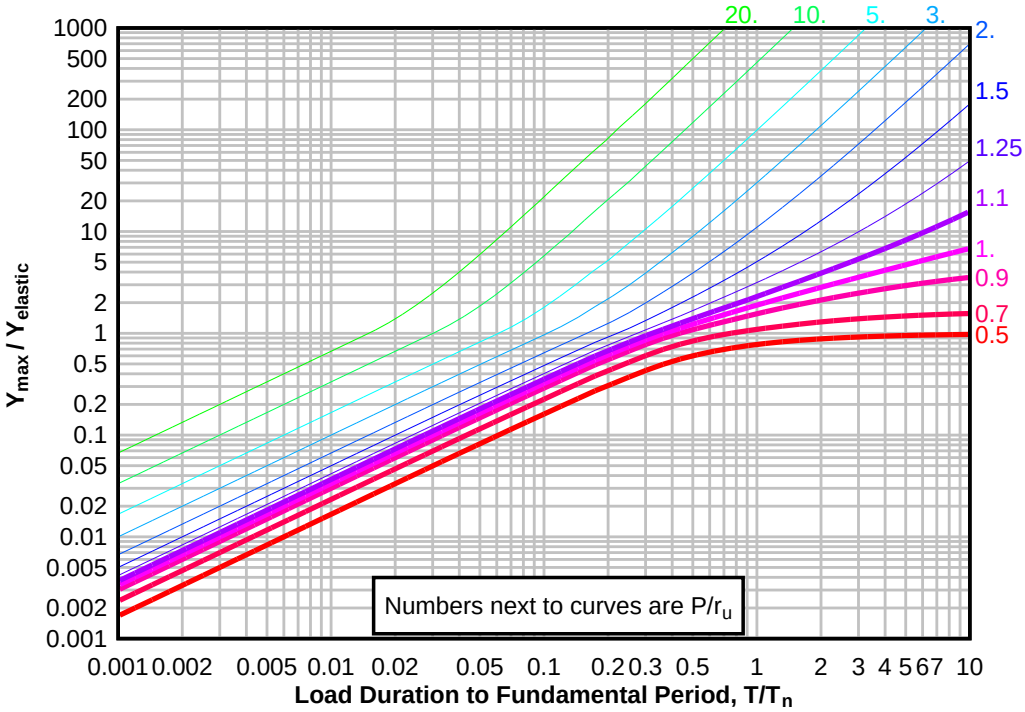


Figure 3-98(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.010, C2 = 5.5)

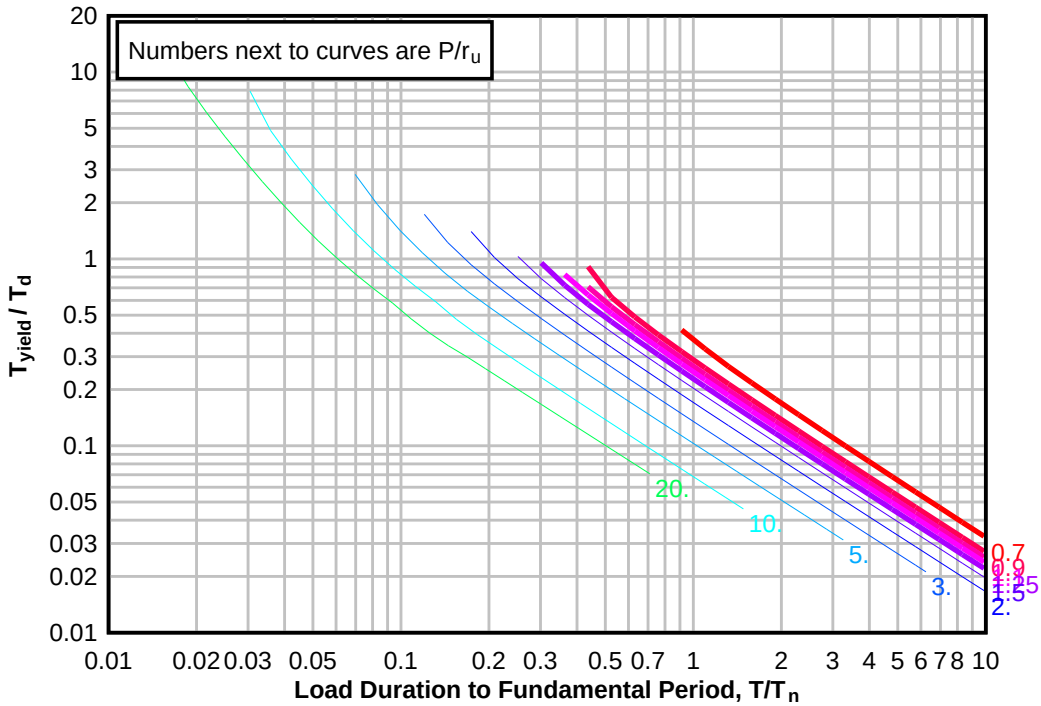


Figure 3-99(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.750, C_2 = 10)

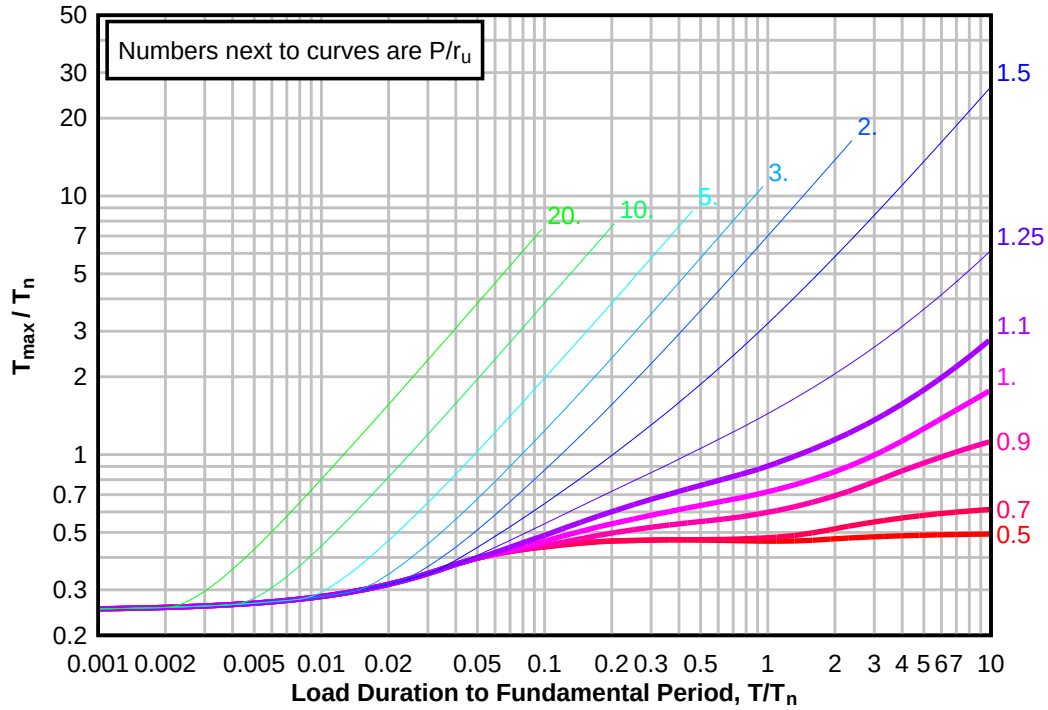


Figure 3-99(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.750, C2 = 10)

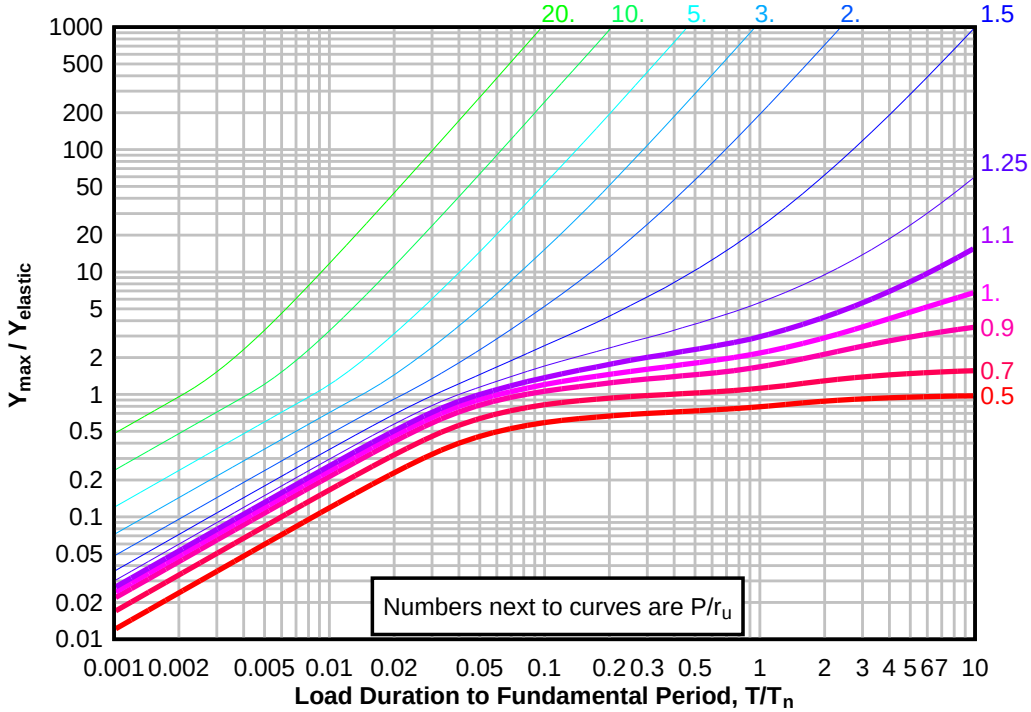


Figure 3-99(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.750, C2 = 10)

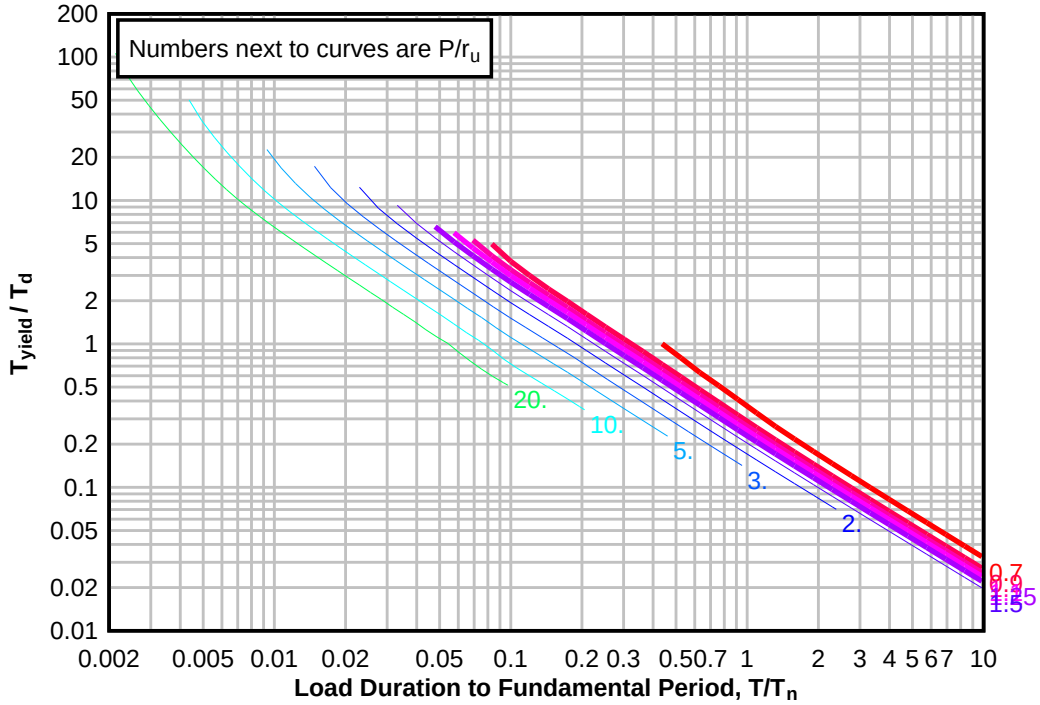


Figure 3-100(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.648, C_2 = 10)

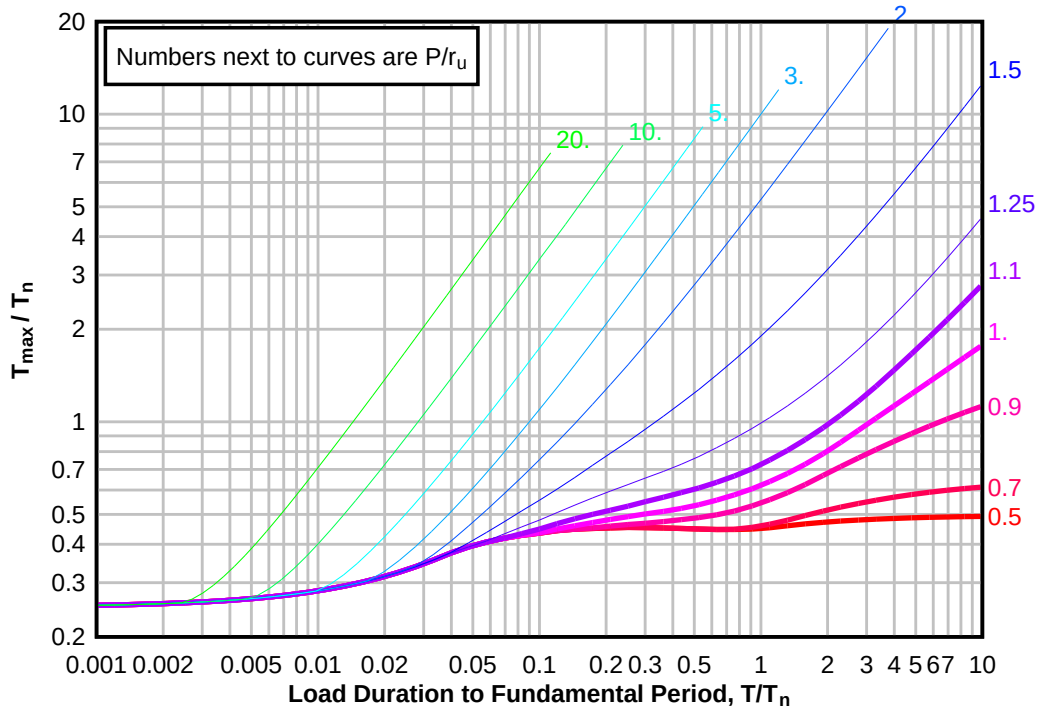


Figure 3-100(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.648, C2 = 10)

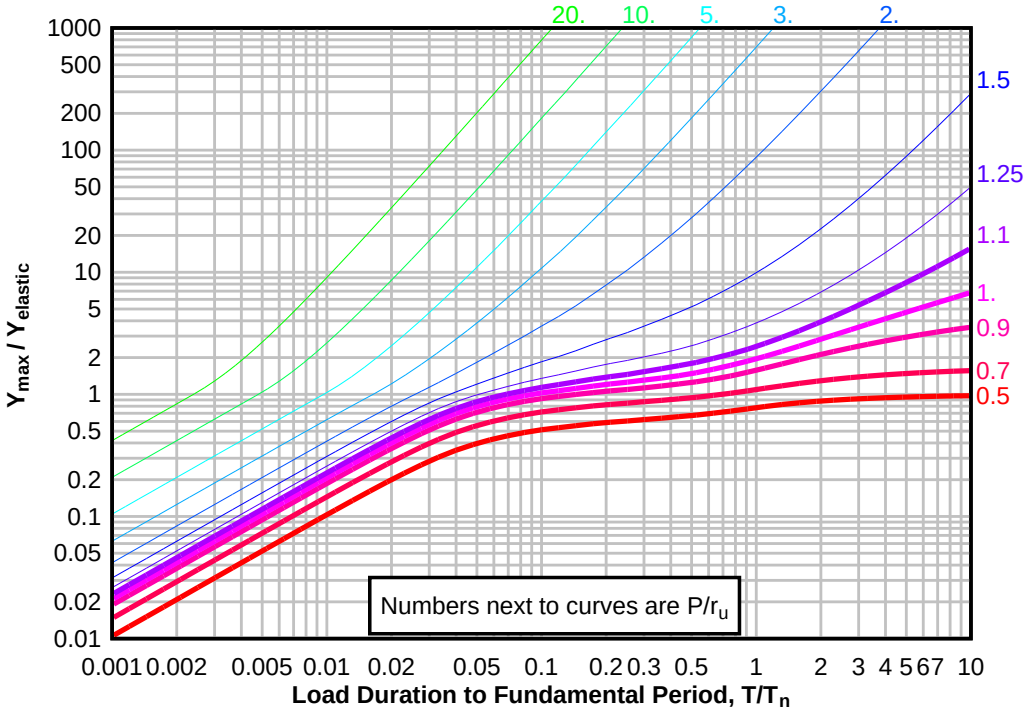


Figure 3-100(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.648, C2 = 10)

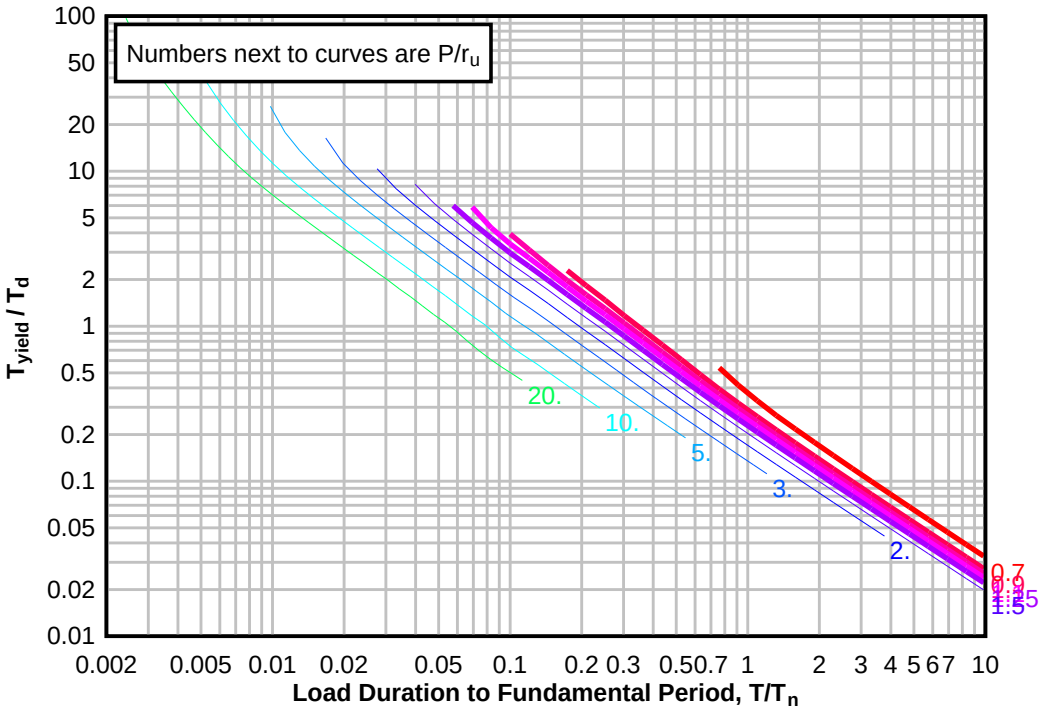


Figure 3-101(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.562, C_2 = 10)

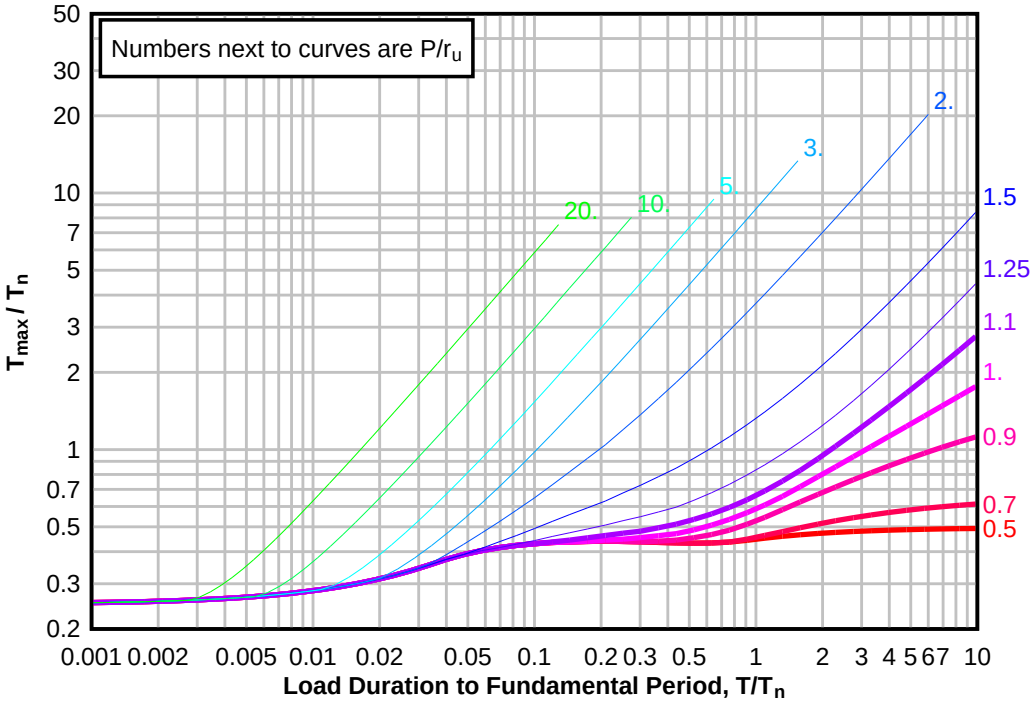


Figure 3-101(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.562, C2 = 10)

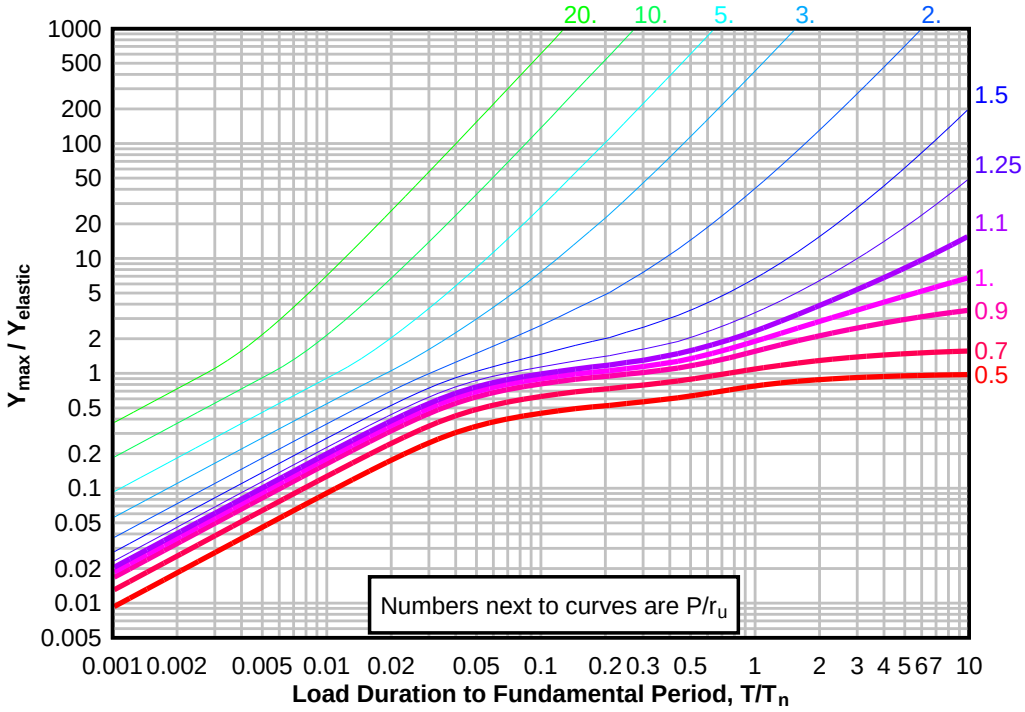


Figure 3-101(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.562, C2 = 10)

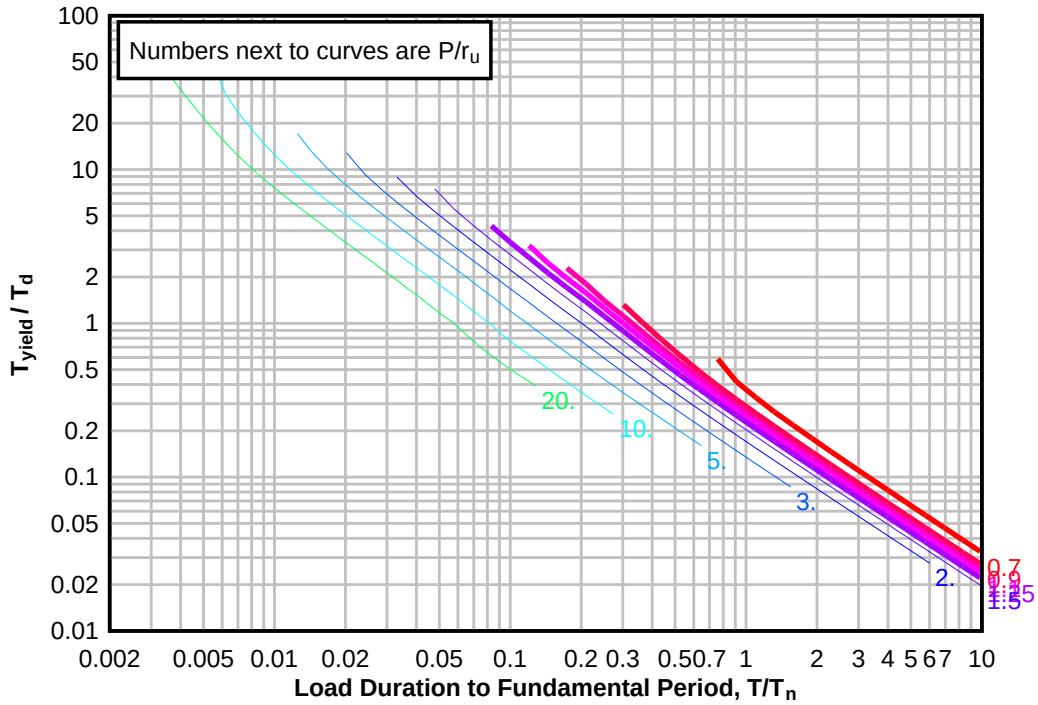


Figure 3-102 (a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.422, C_2 = 10)

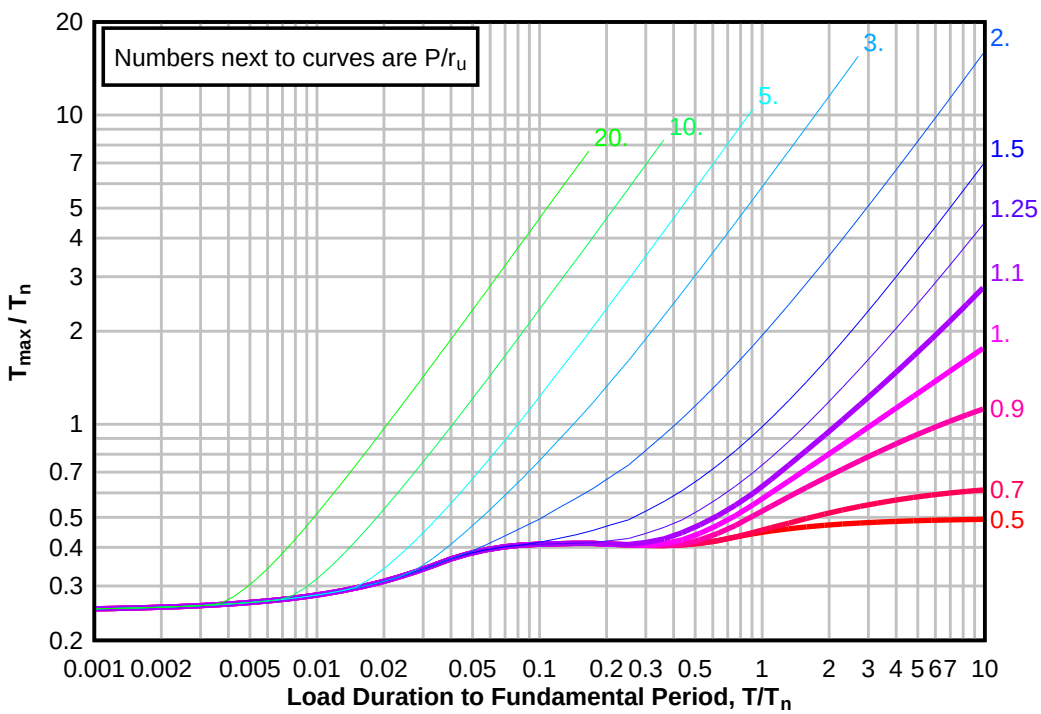


Figure 3-102(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.422, C2 = 10)

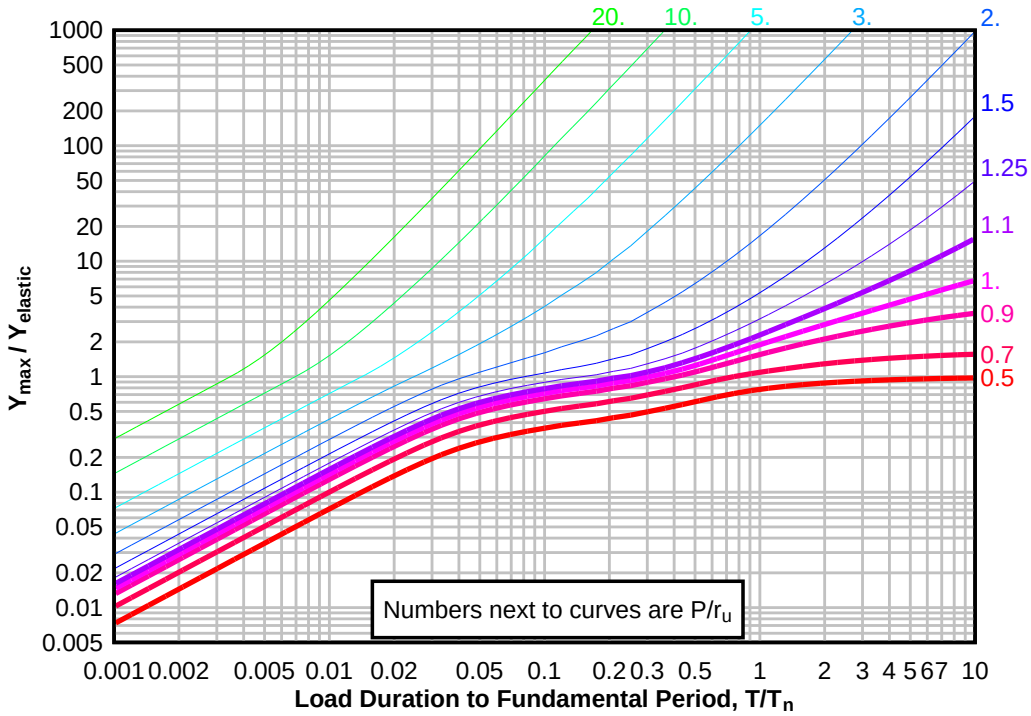


Figure 3-102(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.422, C2 = 10)

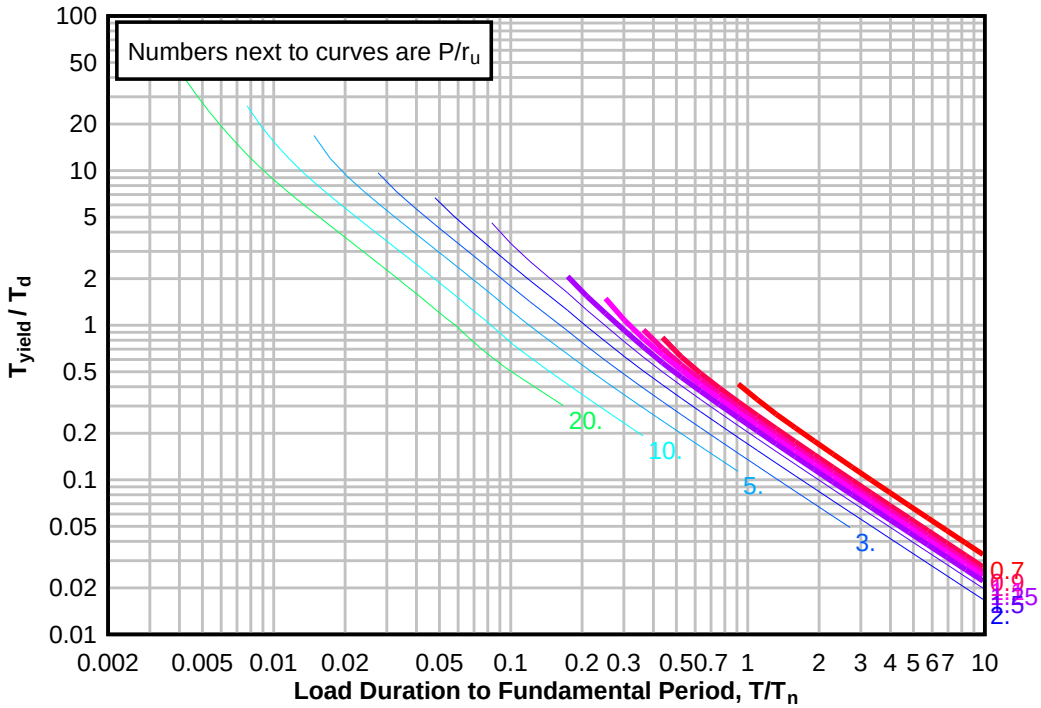


Figure 3-103(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.316, C_2 = 10)

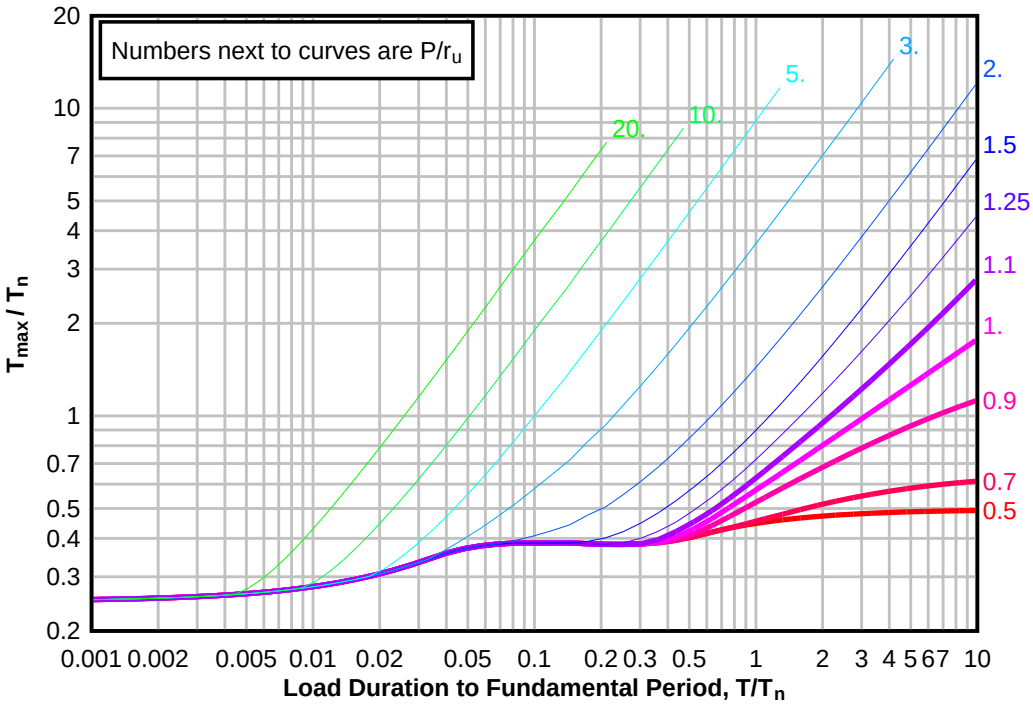


Figure 3-103(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.316, C2 = 10)

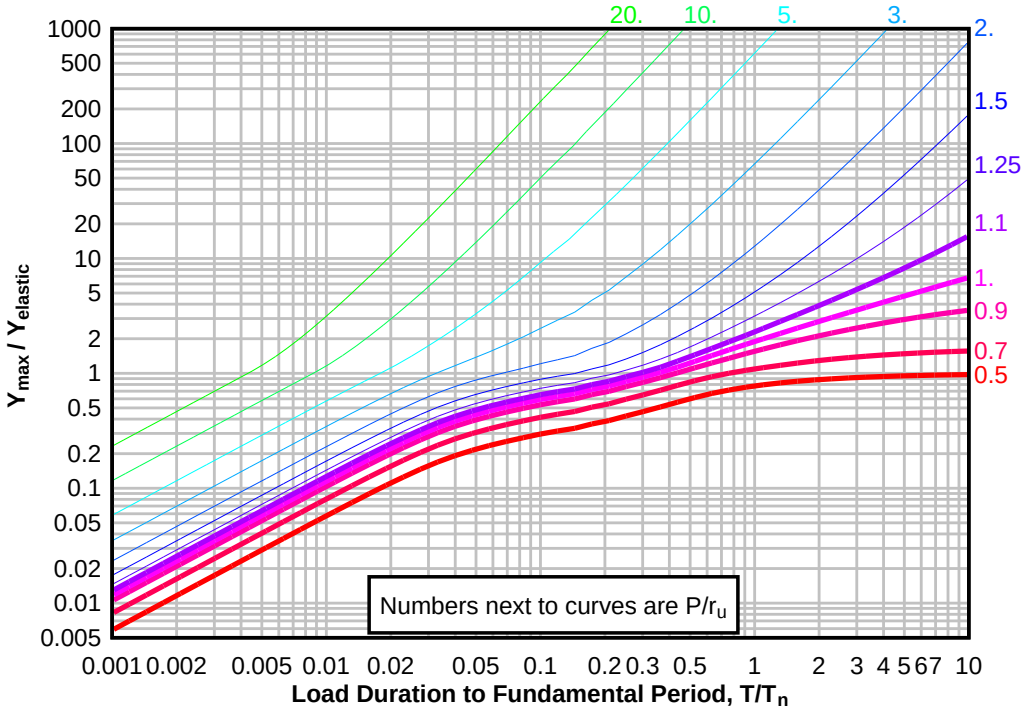


Figure 3-103(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.316, C2 = 10)

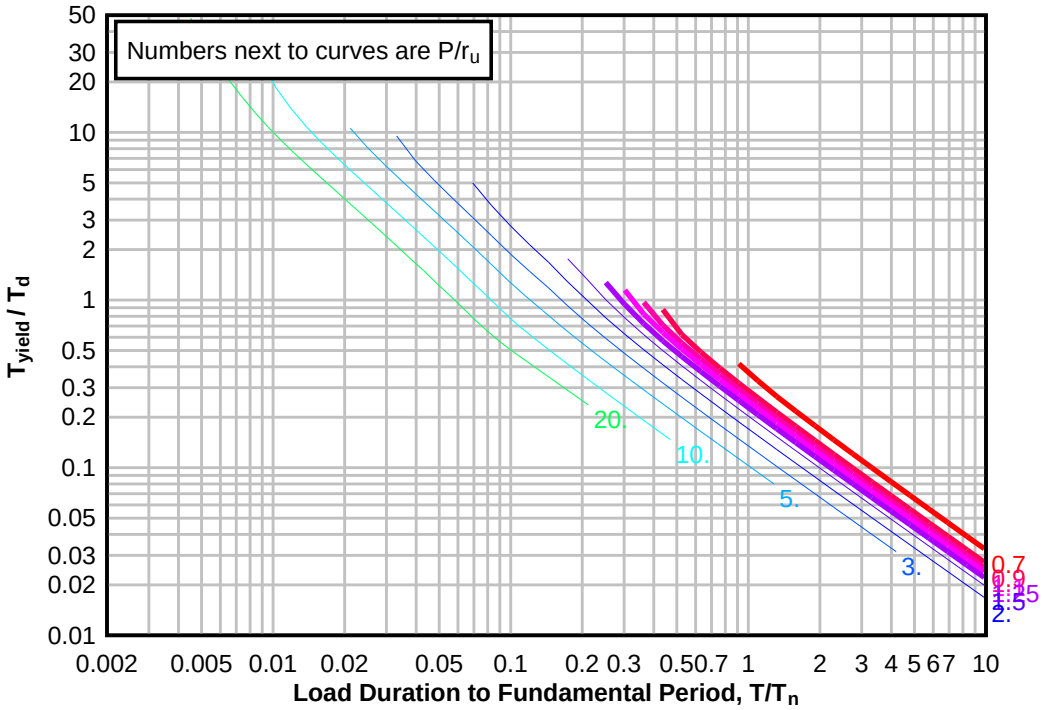


Figure 3-104(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.237, C_2 = 10)

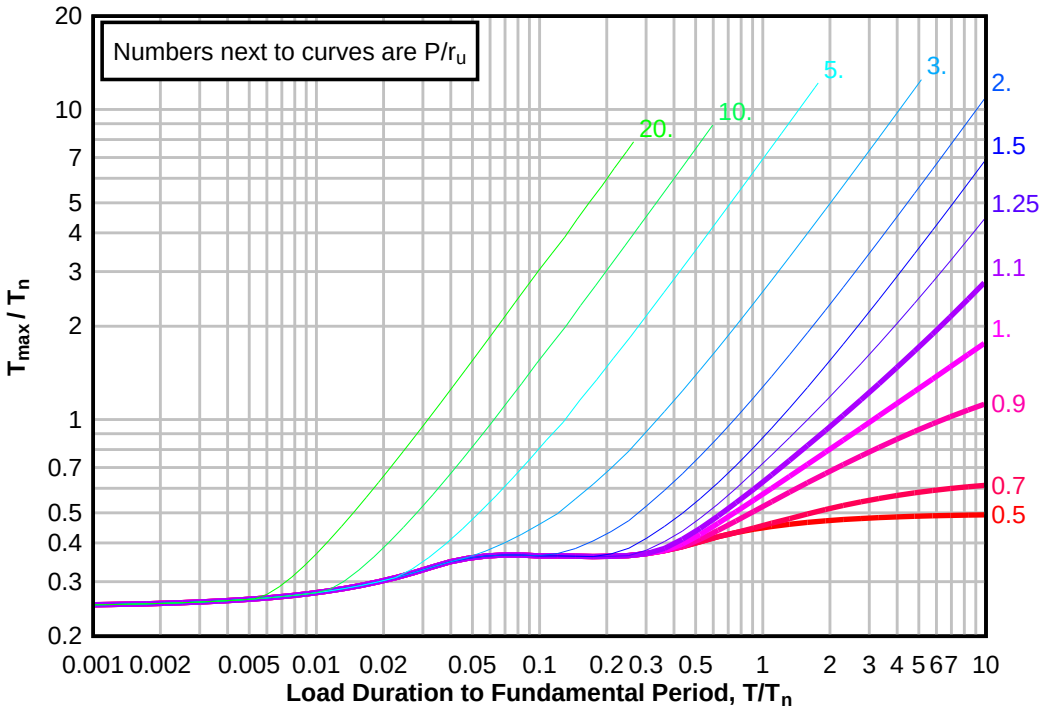


Figure 3-104(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.237, C2 = 10)

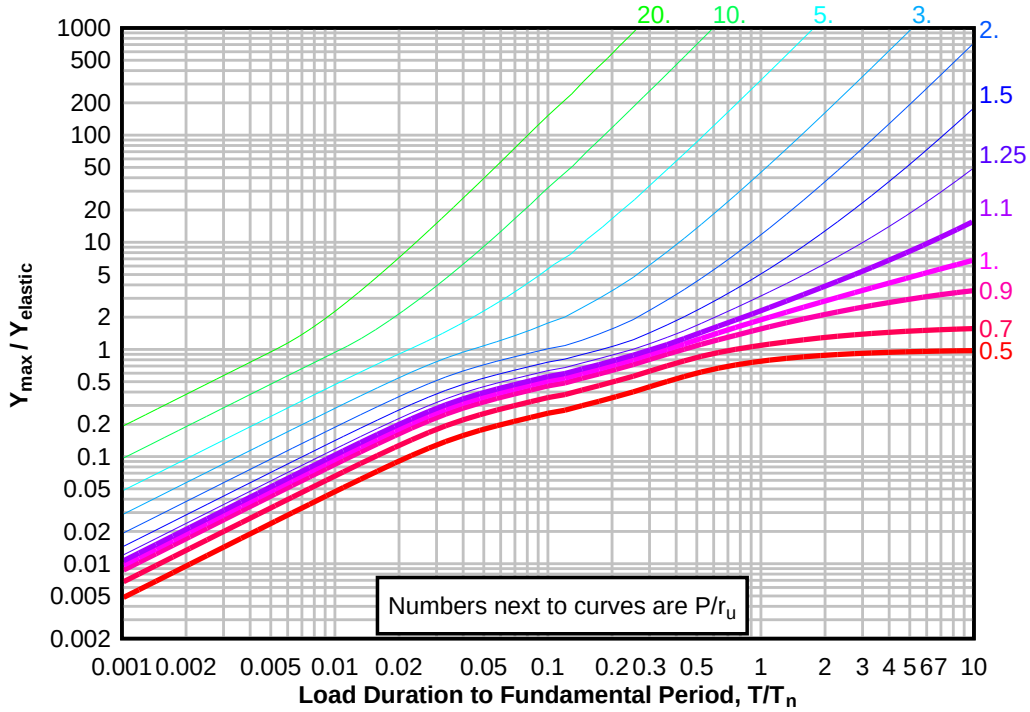


Figure 3-104(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.237, C2 = 10)

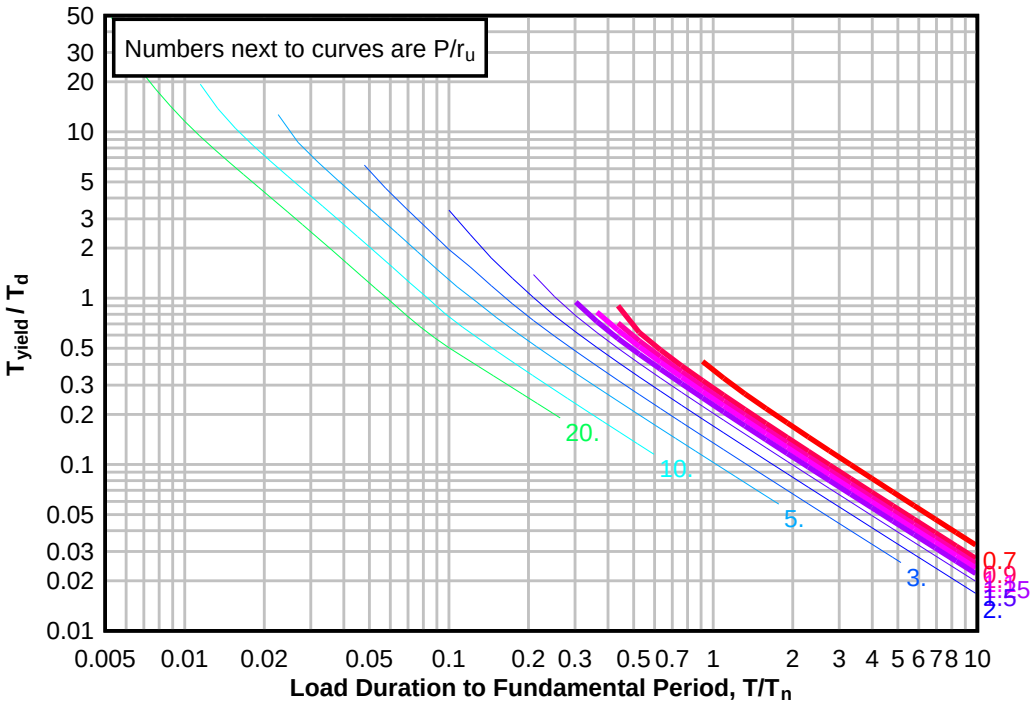


Figure 3-105(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.178, C_2 = 10)

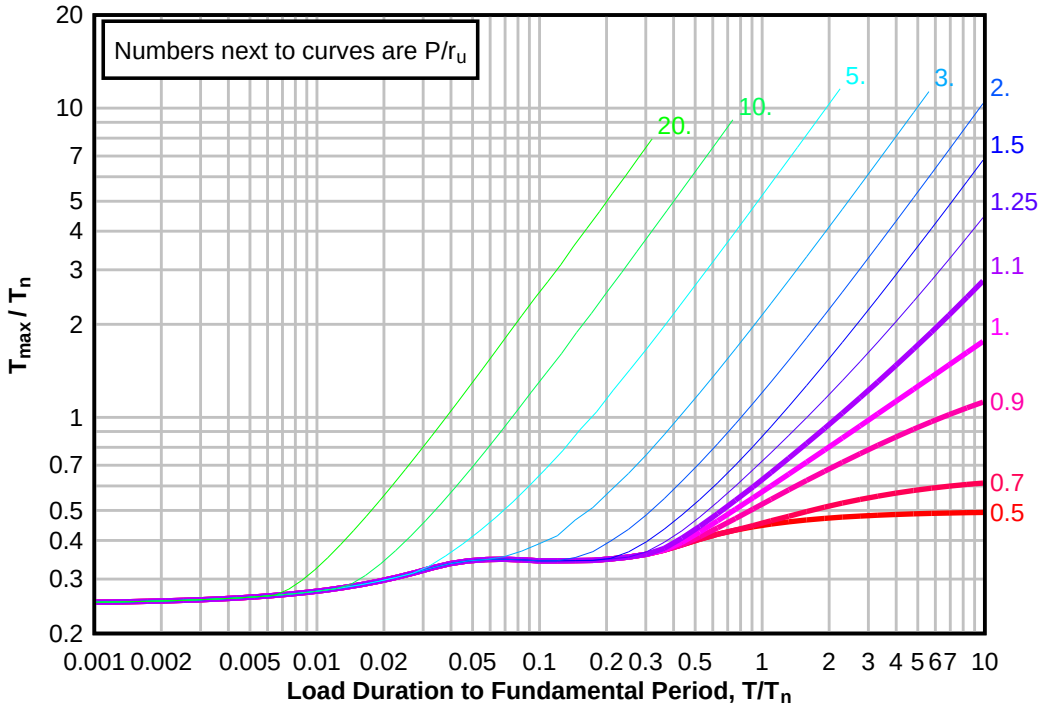


Figure 3-105(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.178, C2 = 10)

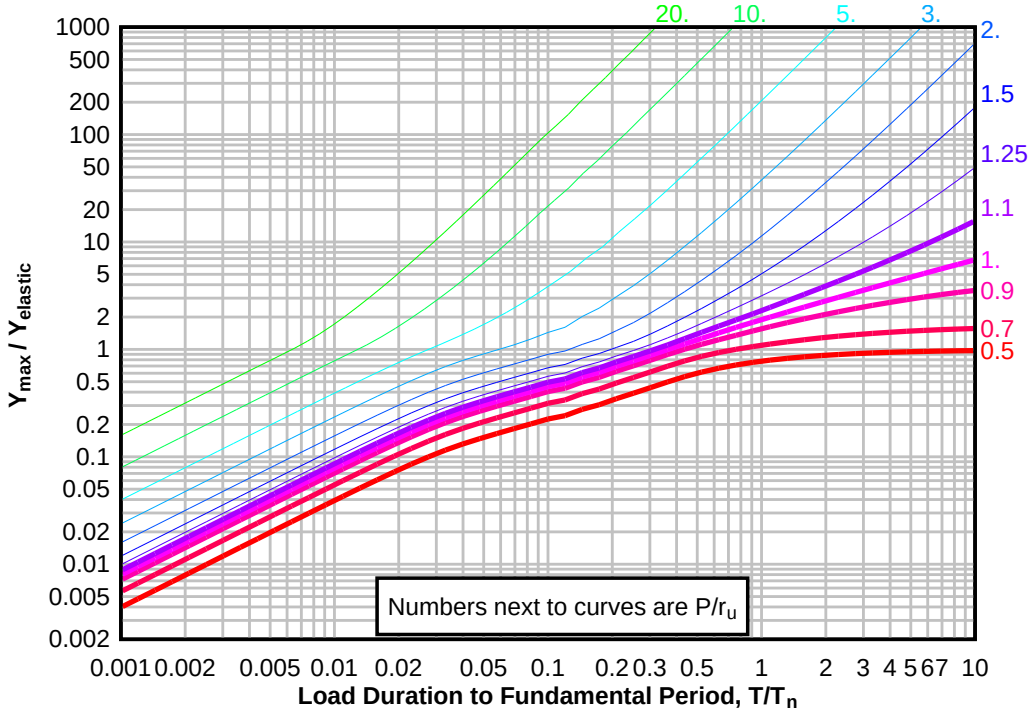


Figure 3-105(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.178, C2 = 10)

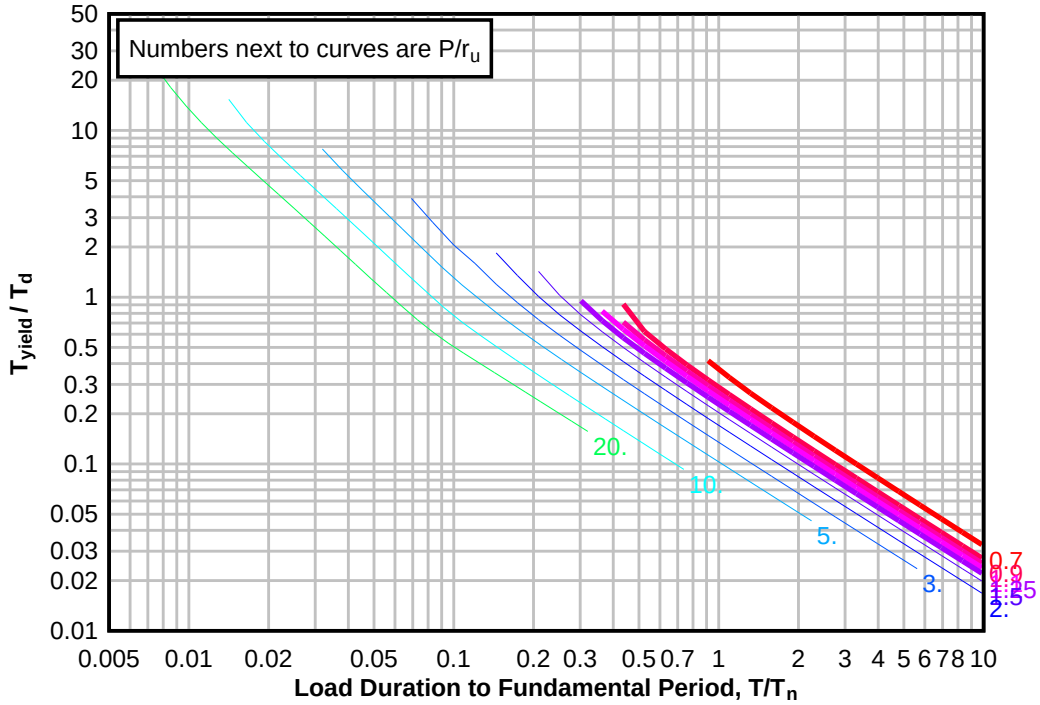


Figure 3-106(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.133, C_2 = 10)

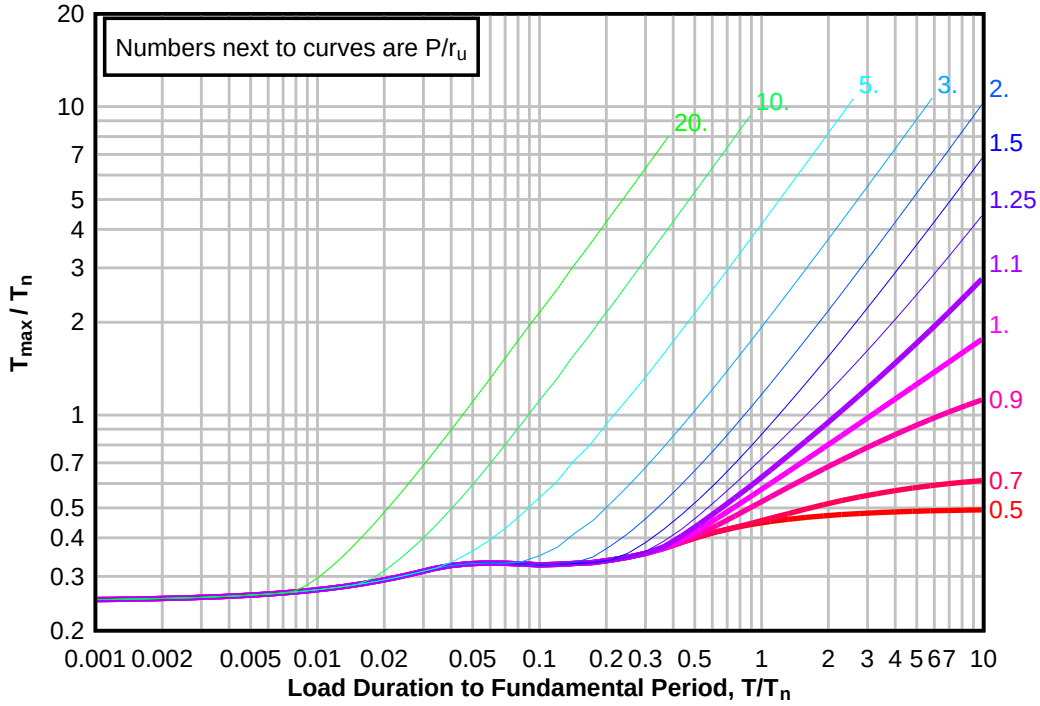


Figure 3-106(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.133, C2 = 10)

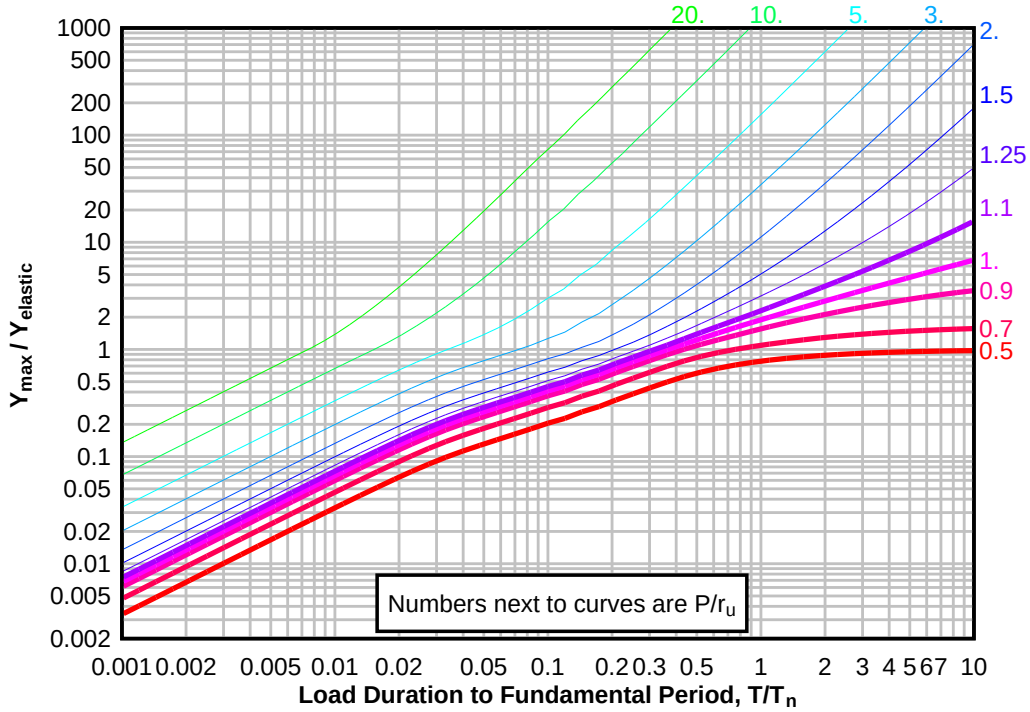


Figure 3-106(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.133, C2 = 10)

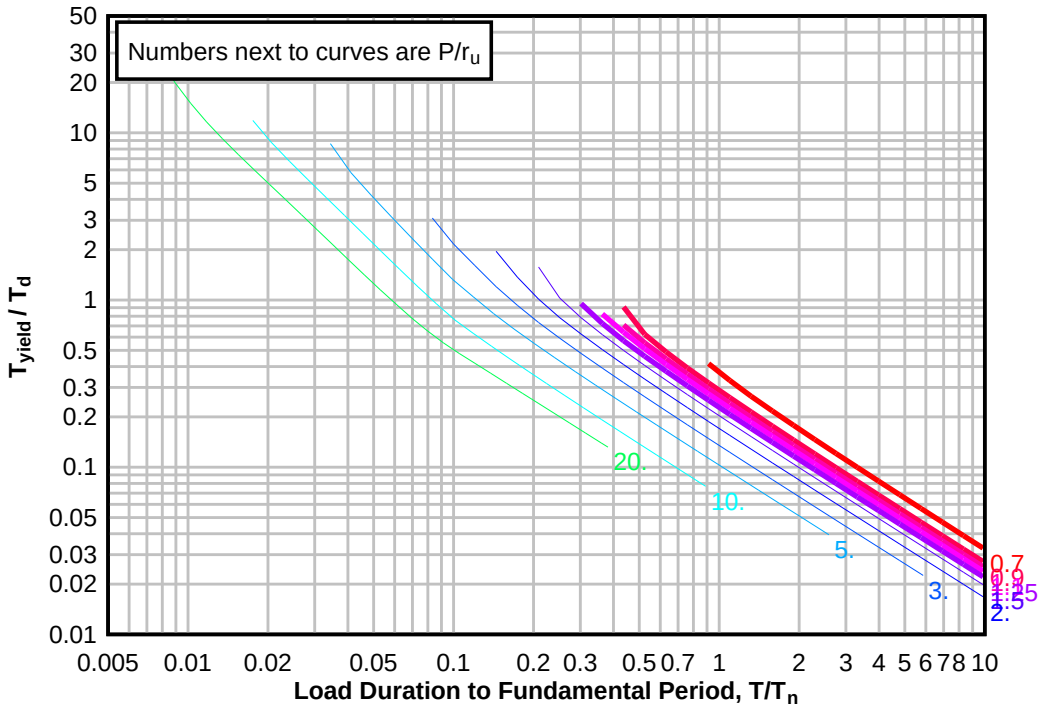


Figure 3-107(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.100, C_2 = 10)

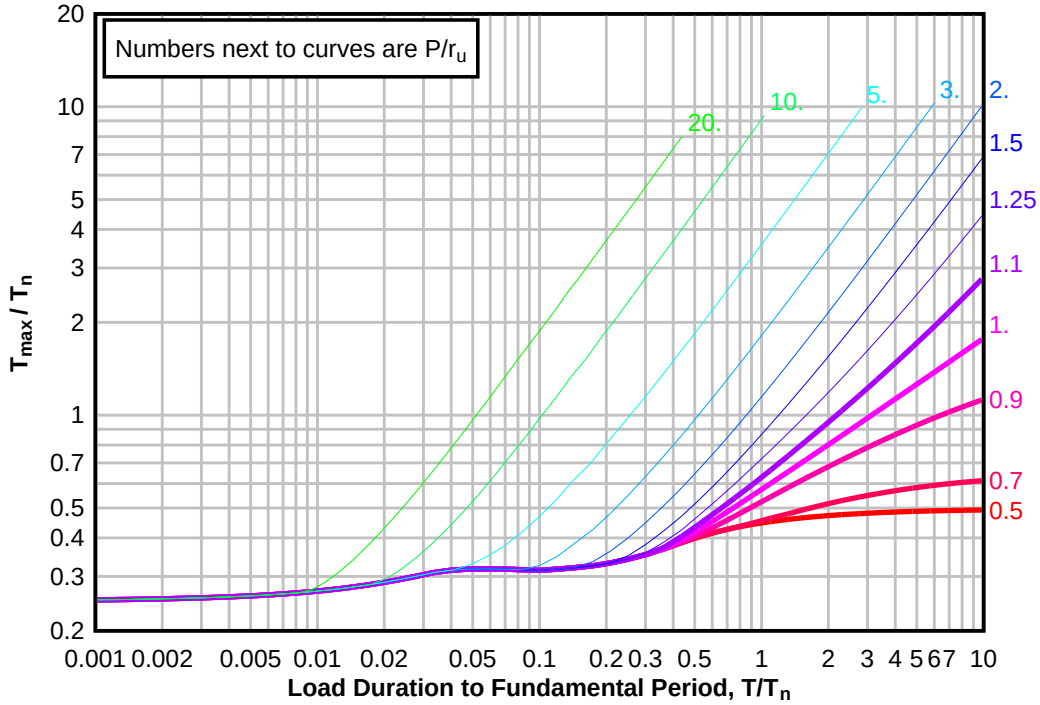


Figure 3-107(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.100, C2 = 10)

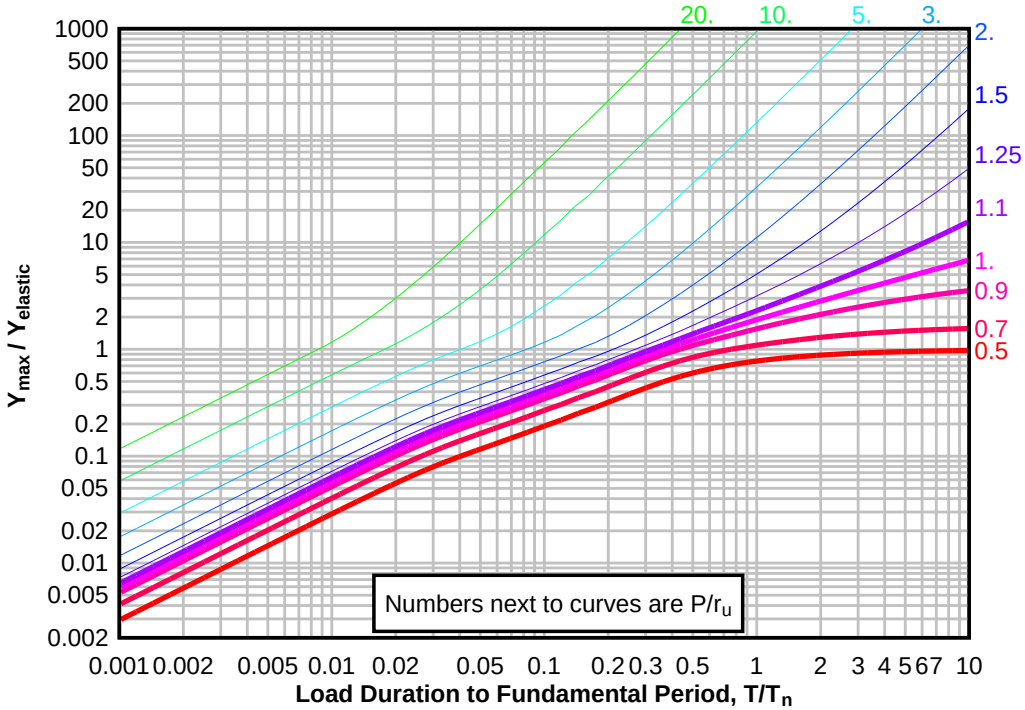


Figure 3-107(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.100, C2 = 10)

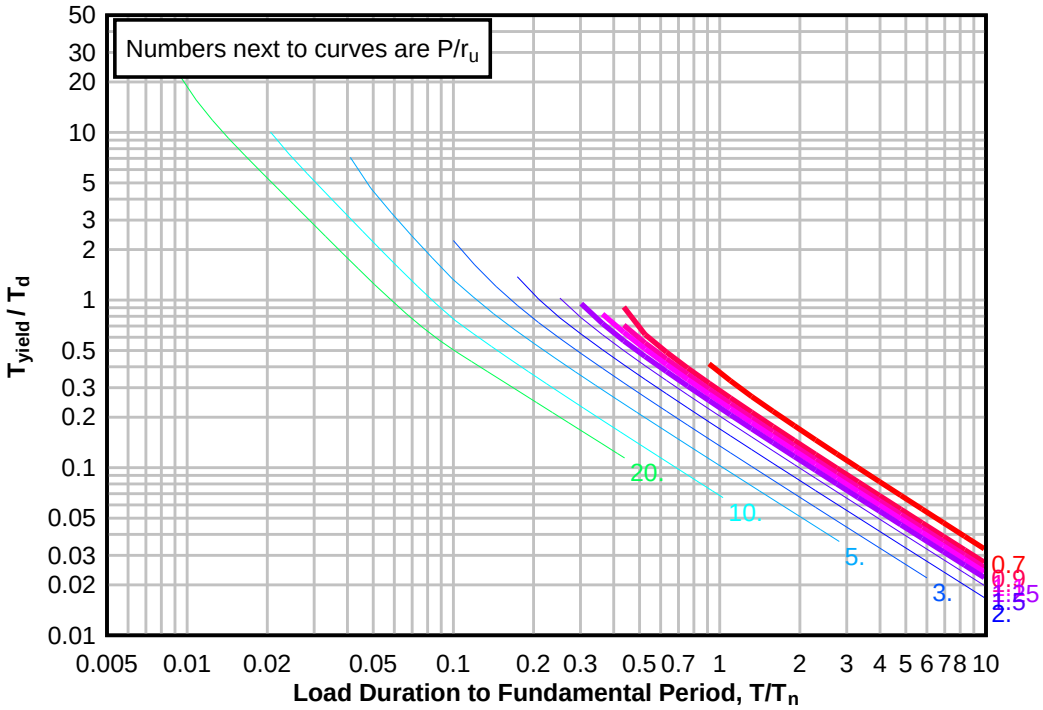


Figure 3-108(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.068, C_2 = 10)

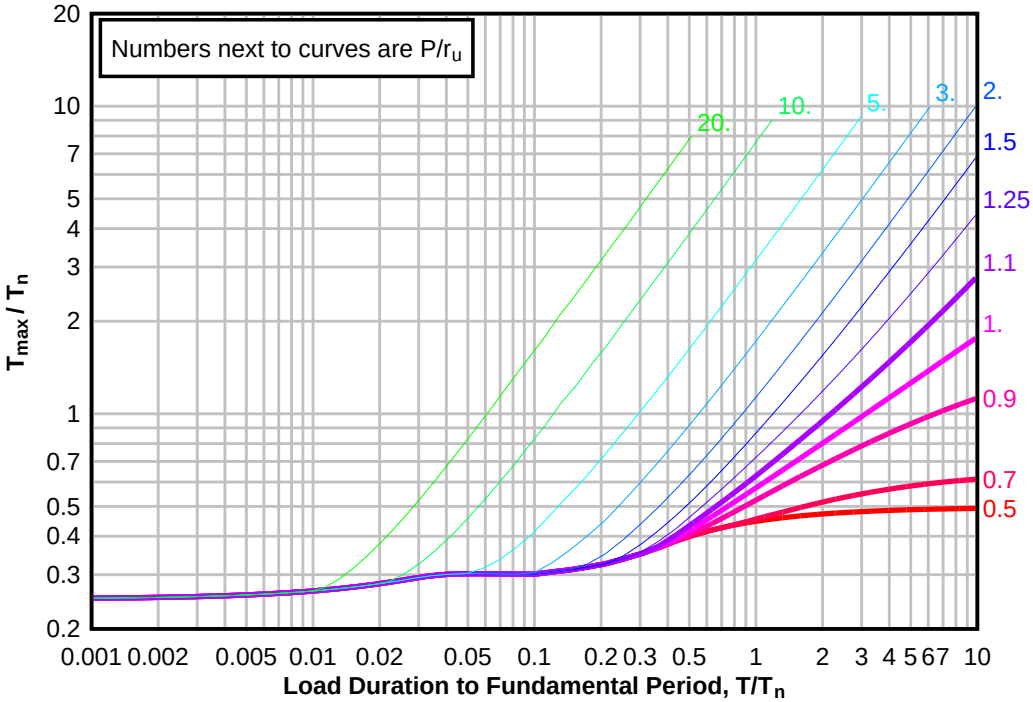


Figure 3-108(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.068, C2 = 10)

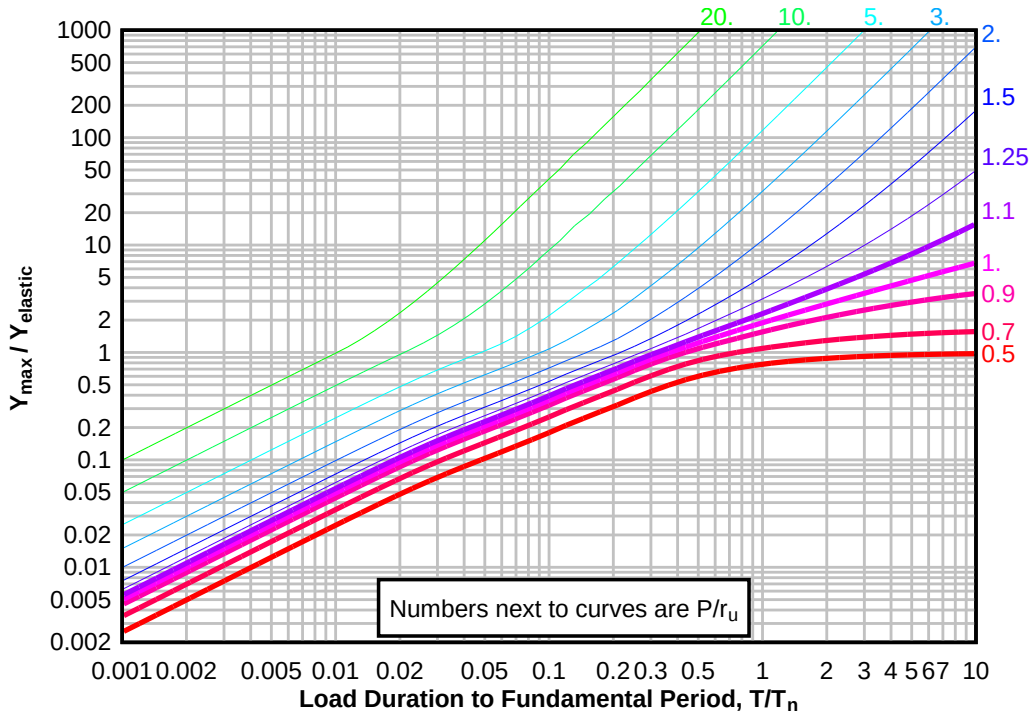


Figure 3-108(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.068, C2 = 10)

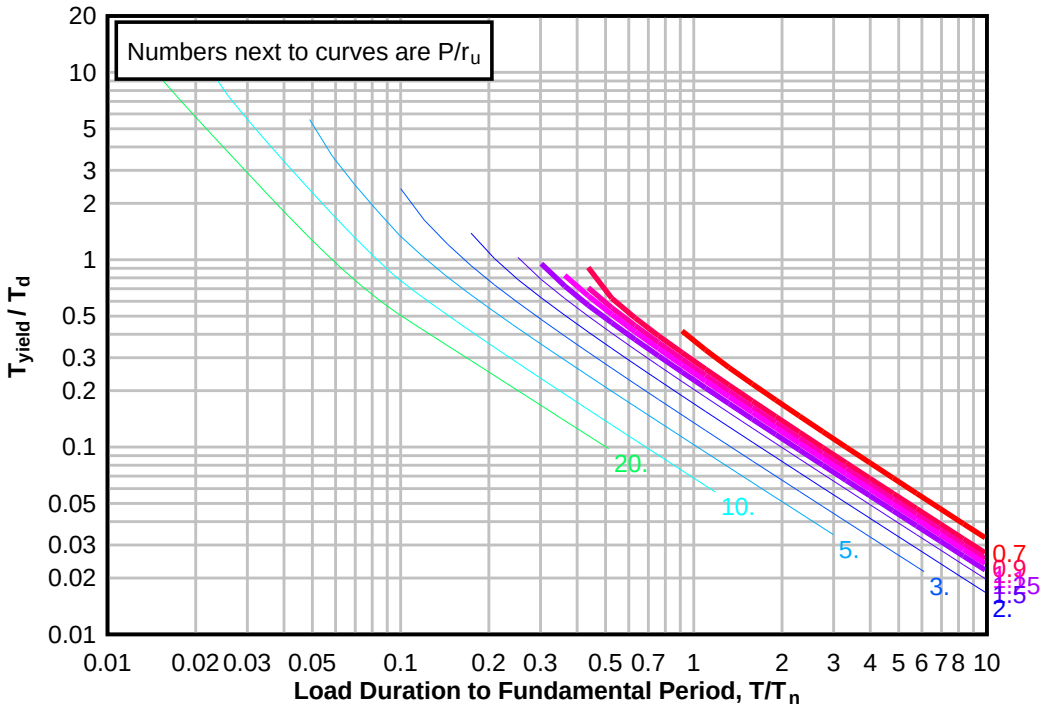


Figure 3-109(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.046, C_2 = 10)

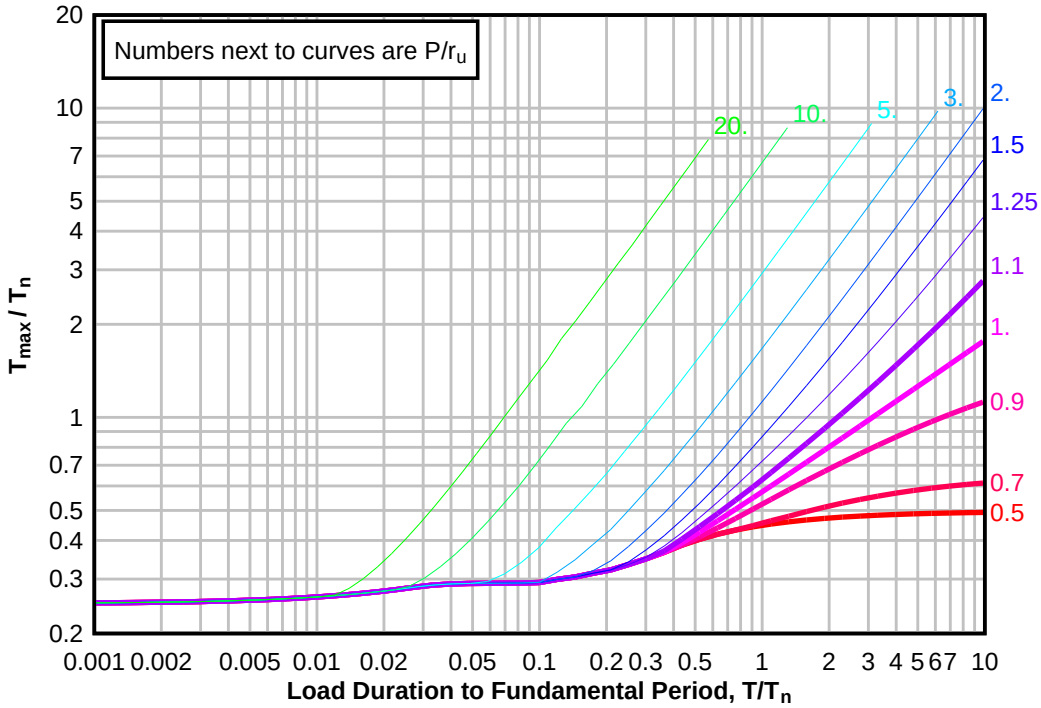


Figure 3-109(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.046, C2 = 10)

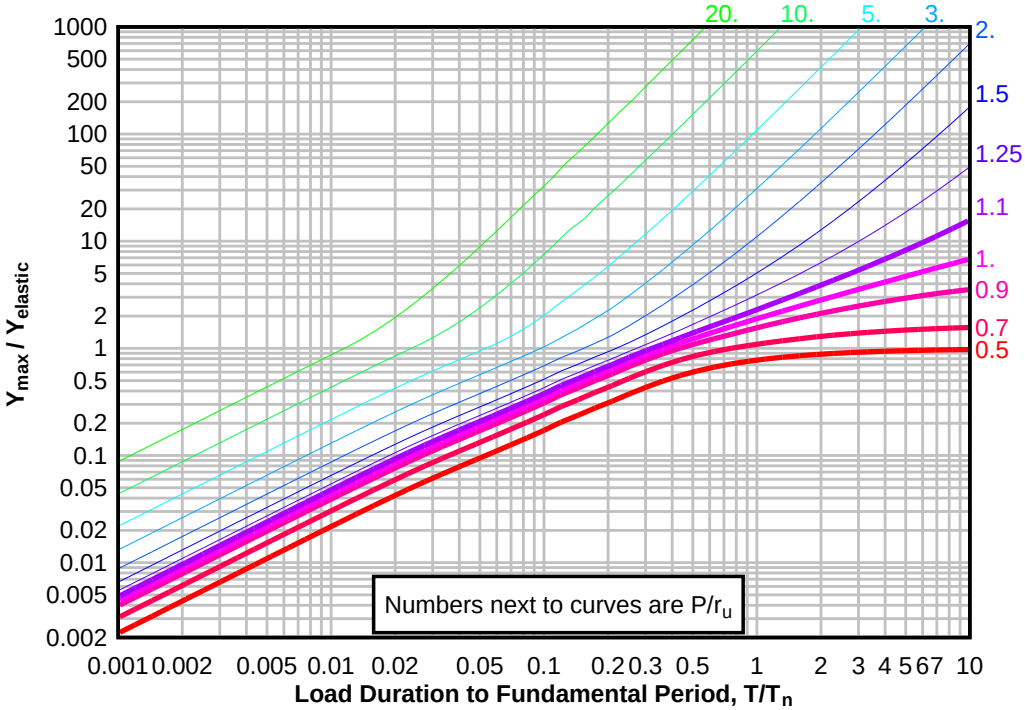


Figure 3-109(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.046, C2 = 10)

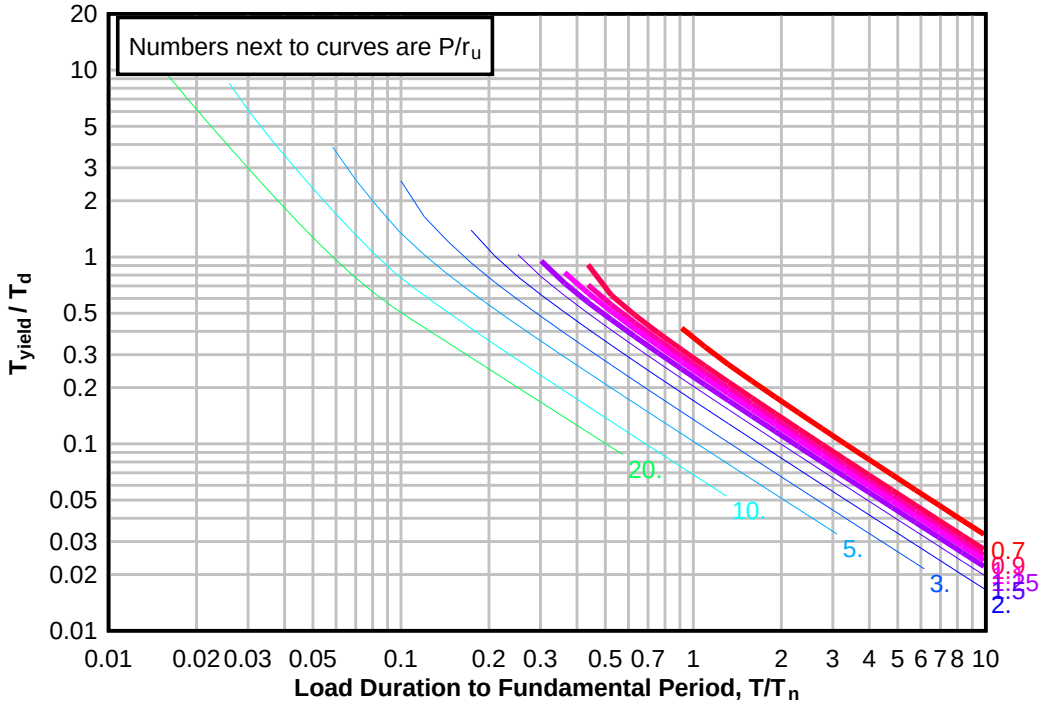


Figure 3-110(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.032, C_2 = 10)

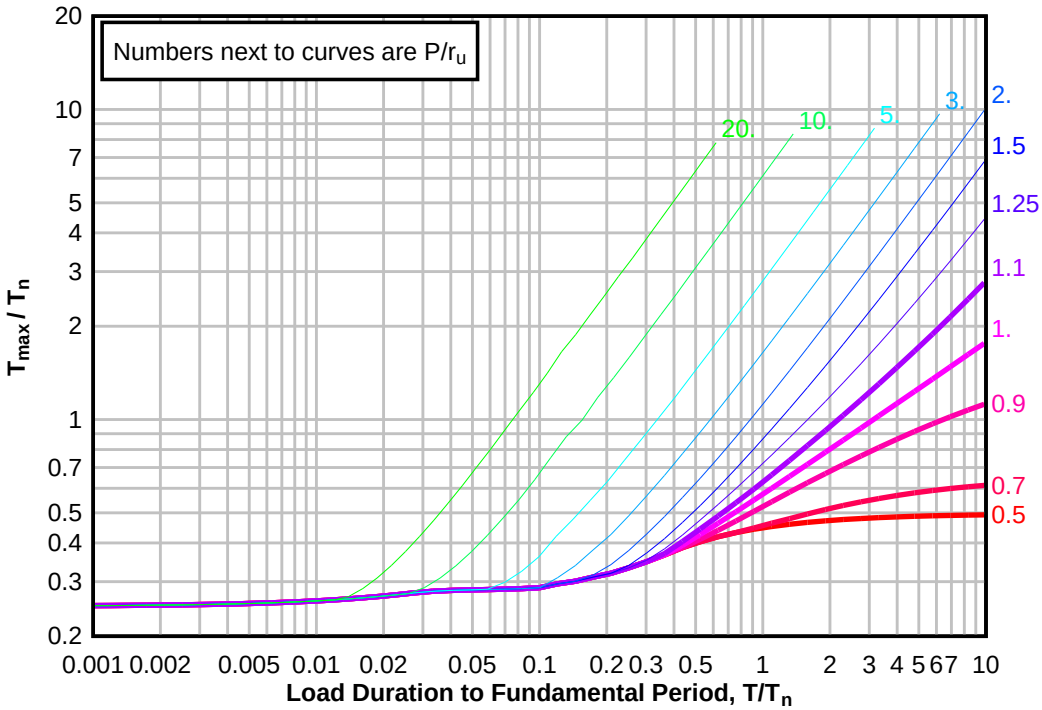


Figure 3-110(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.032, C2 = 10)

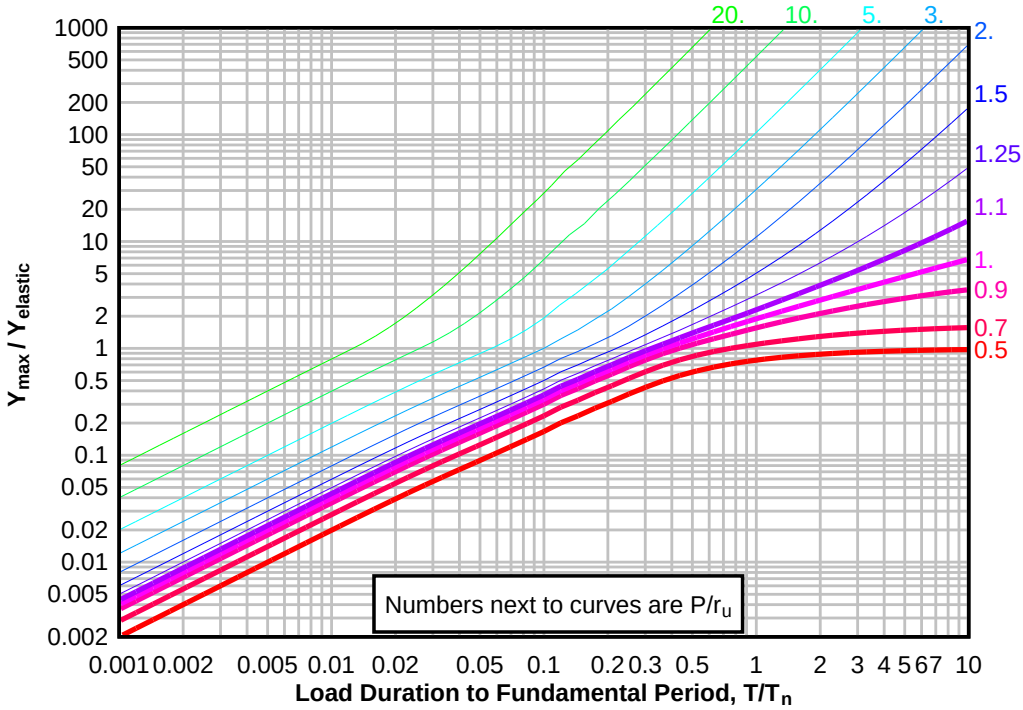


Figure 3-110(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.032, C2 = 10)

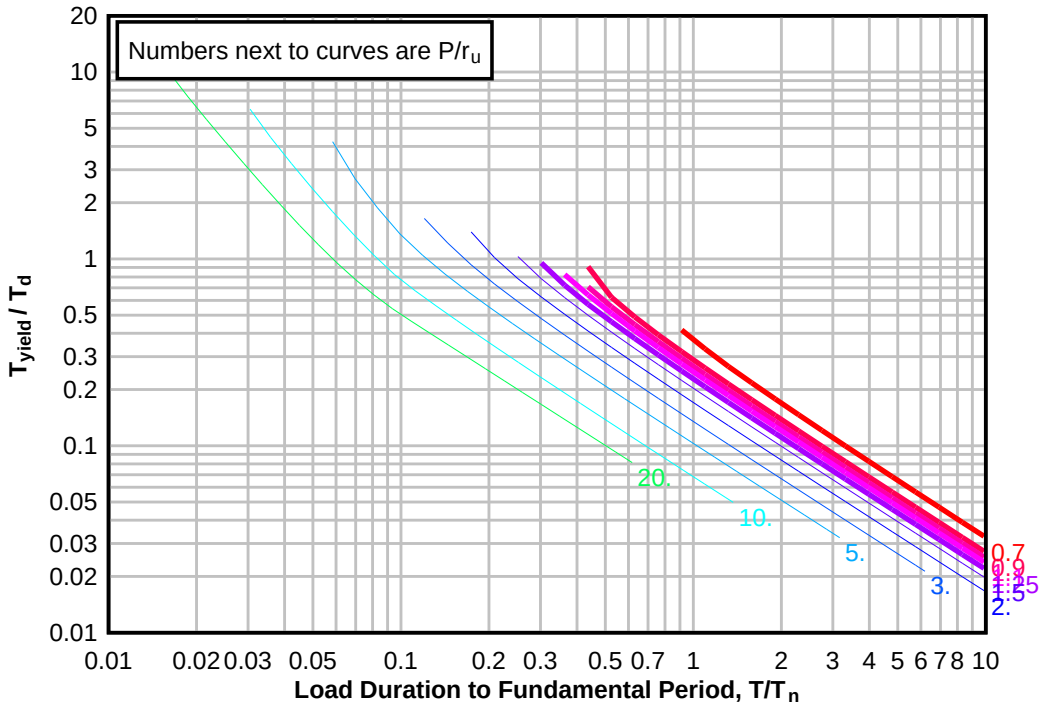


Figure 3-111(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.022, C_2 = 10)

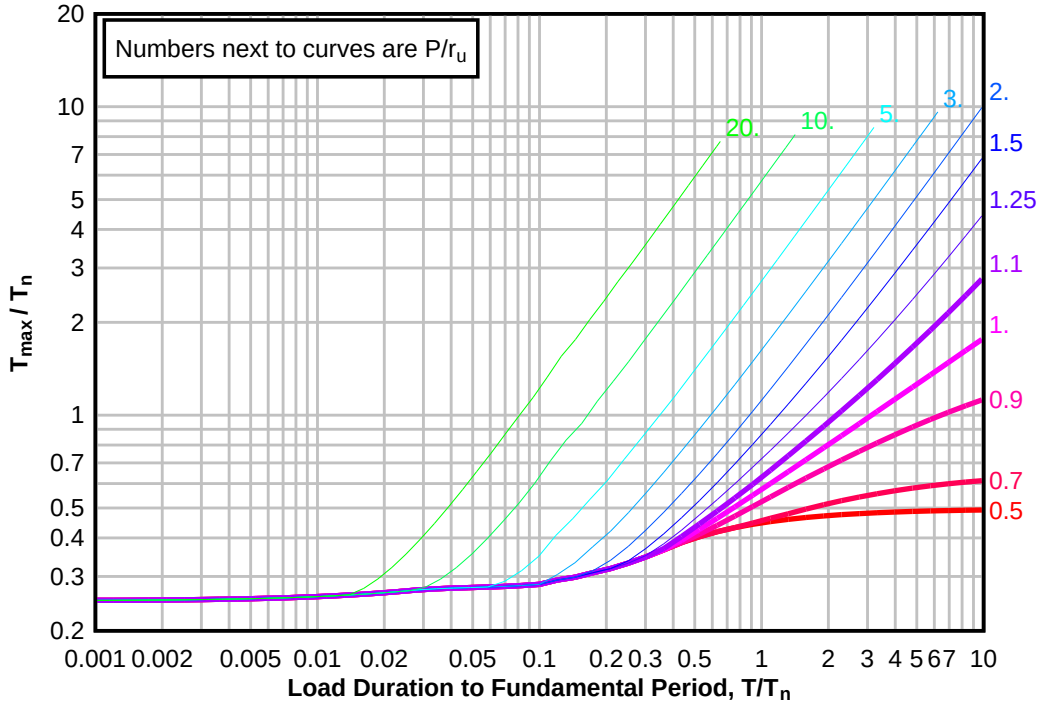


Figure 3-111(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.022, C2 = 10)

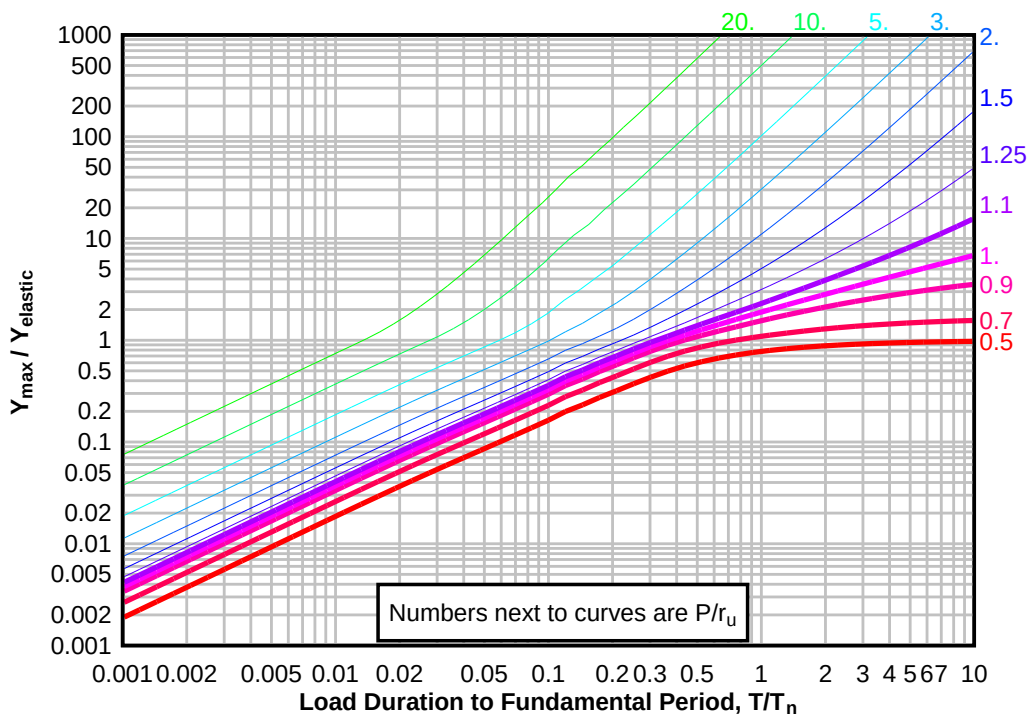


Figure 3-111(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.022, C2 = 10)

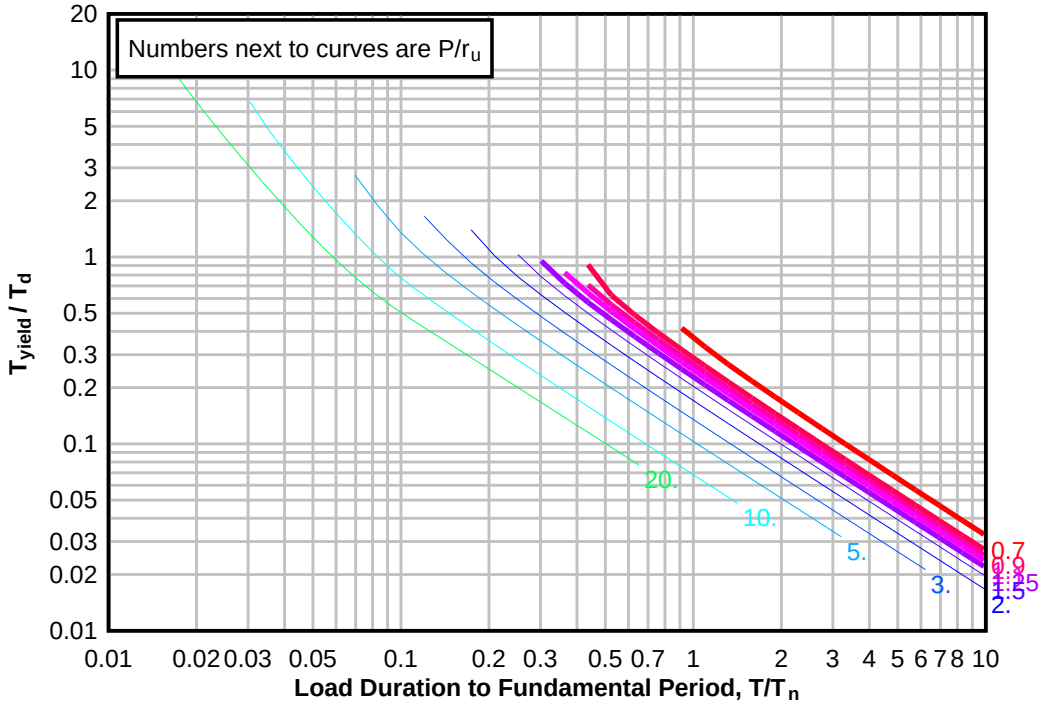


Figure 3-112 (a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.015, C_2 = 10)

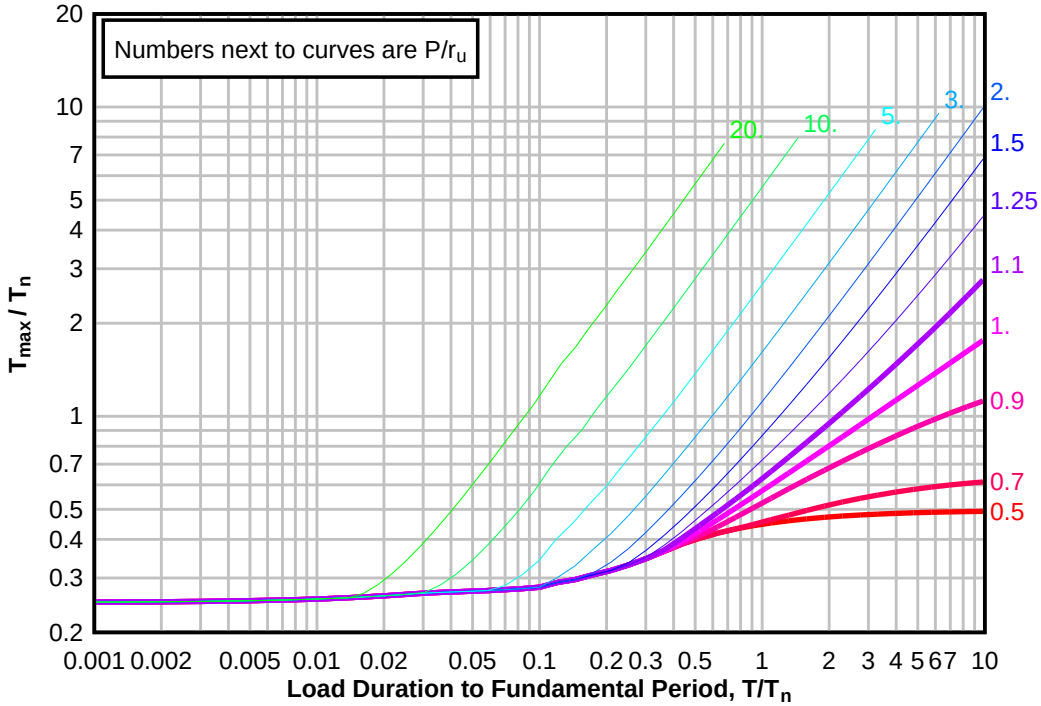


Figure 3-112(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.015, C2 = 10)

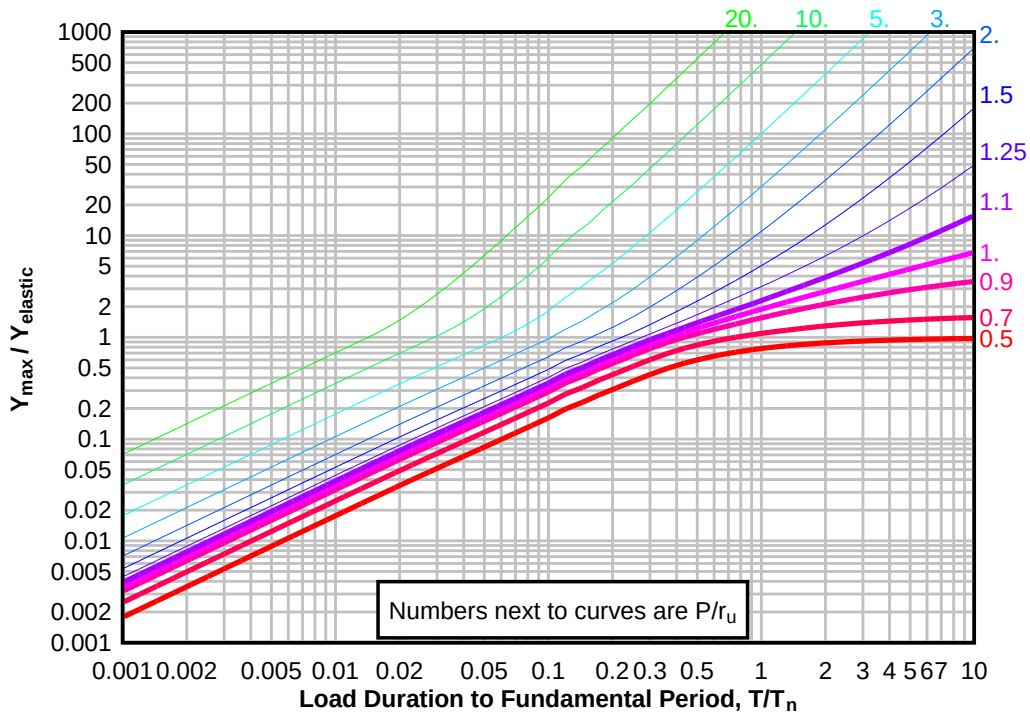


Figure 3-112(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.015, C2 = 10)

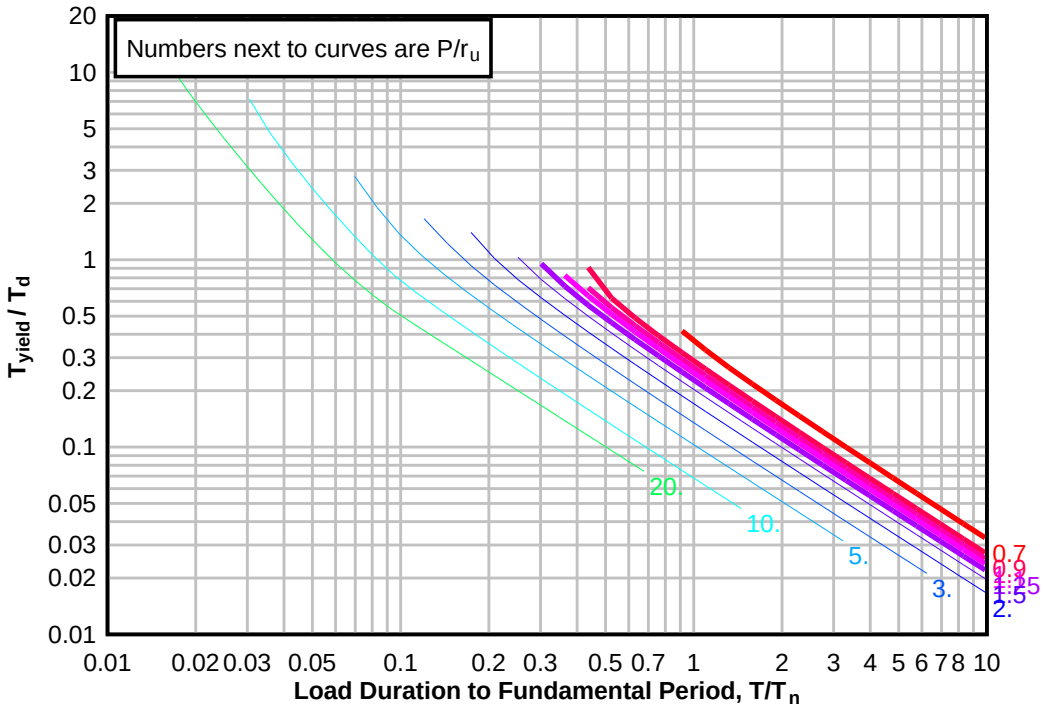


Figure 3-113(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.010, C_2 = 10)

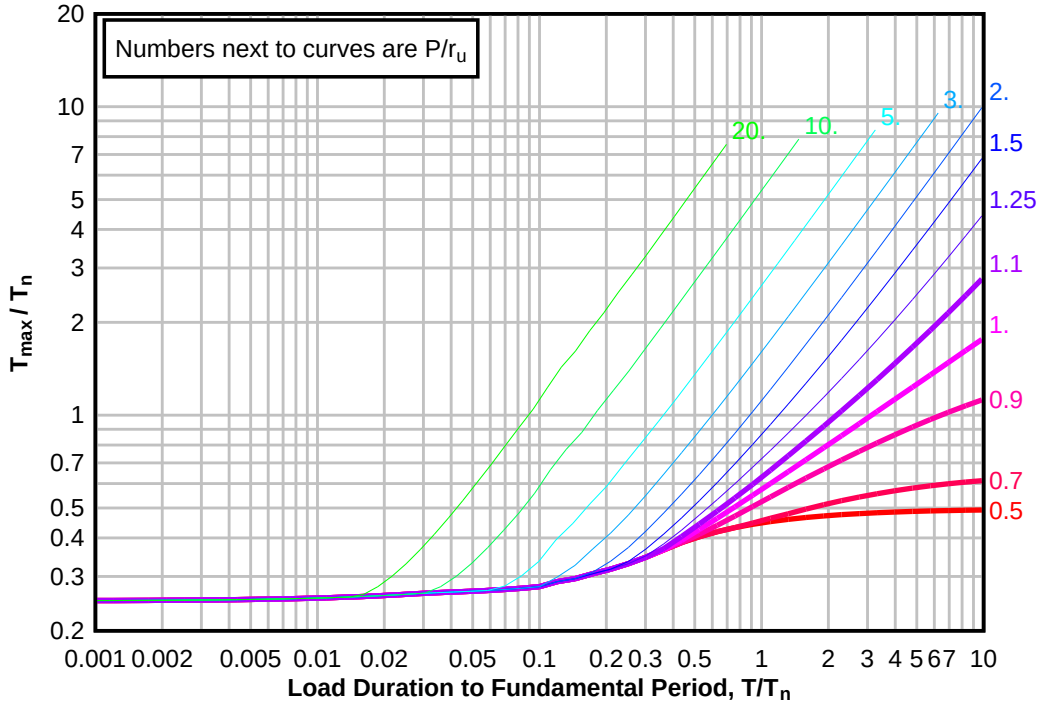


Figure 3-113(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.010, C2 = 10)

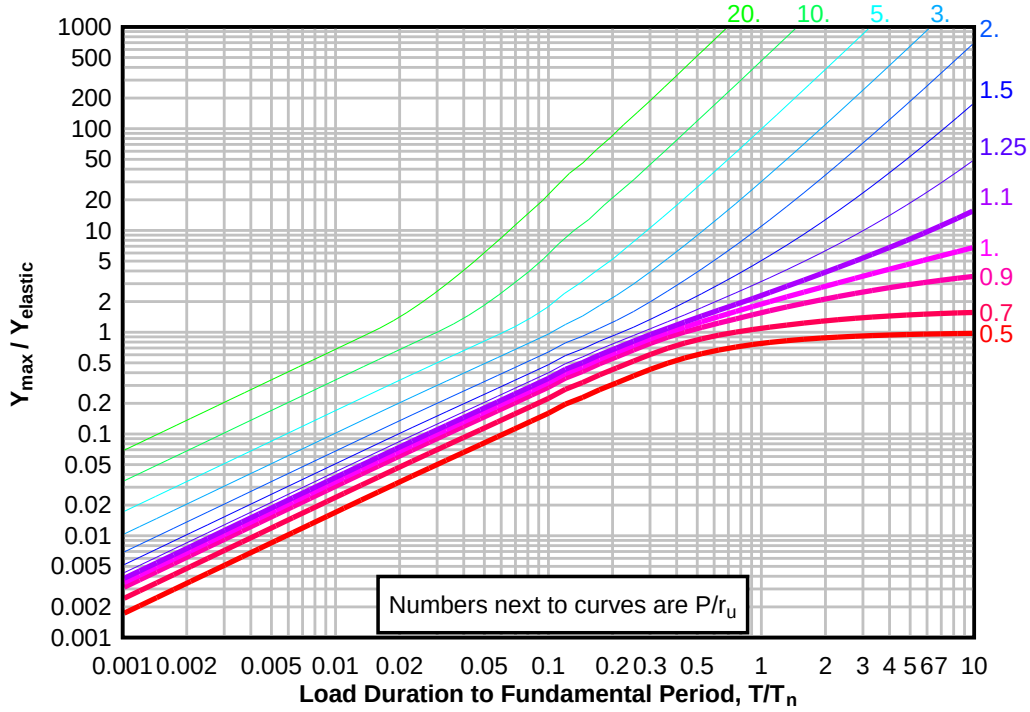


Figure 3-113(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.010, C2 = 10)

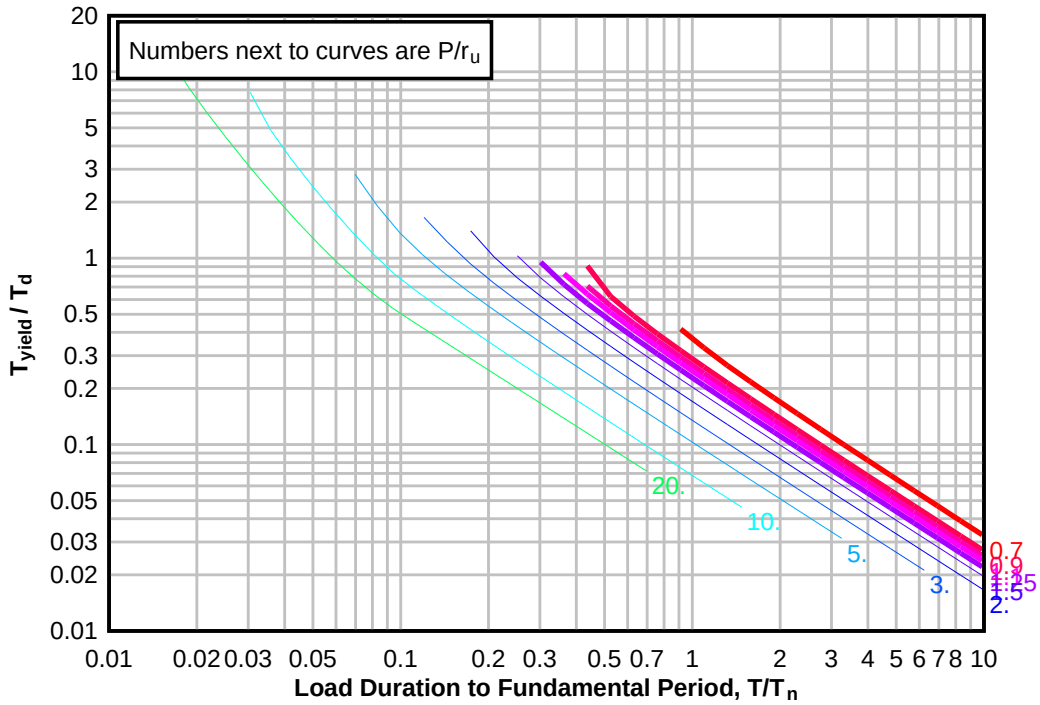


Figure 3-114 (a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.909, C_2 = 30)

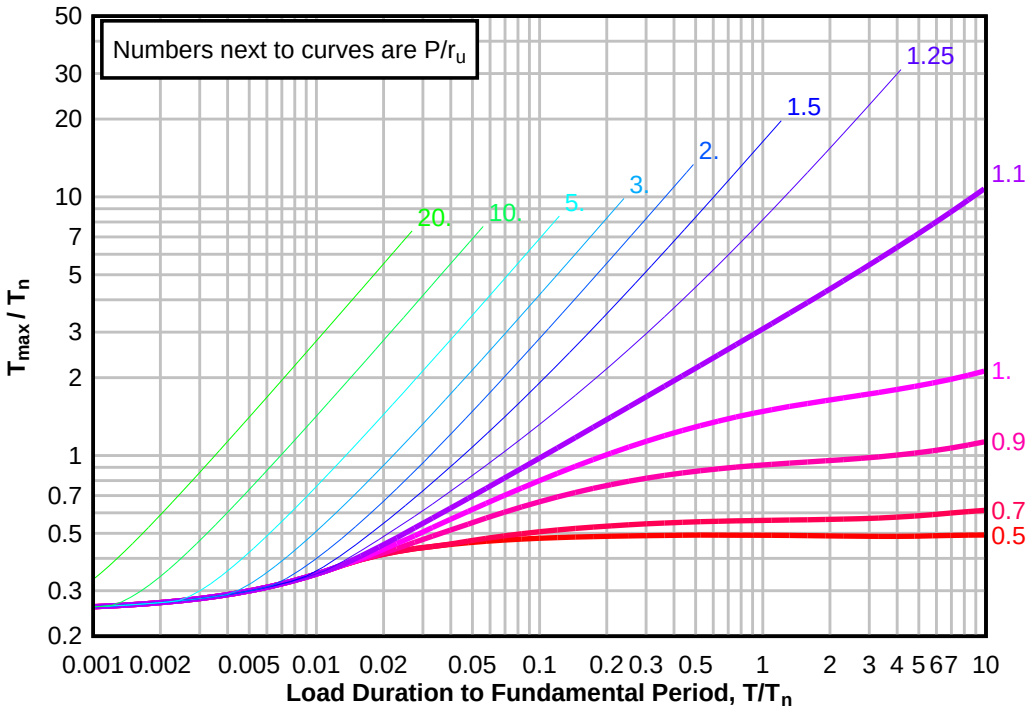


Figure 3-114(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.909, C2 = 30)

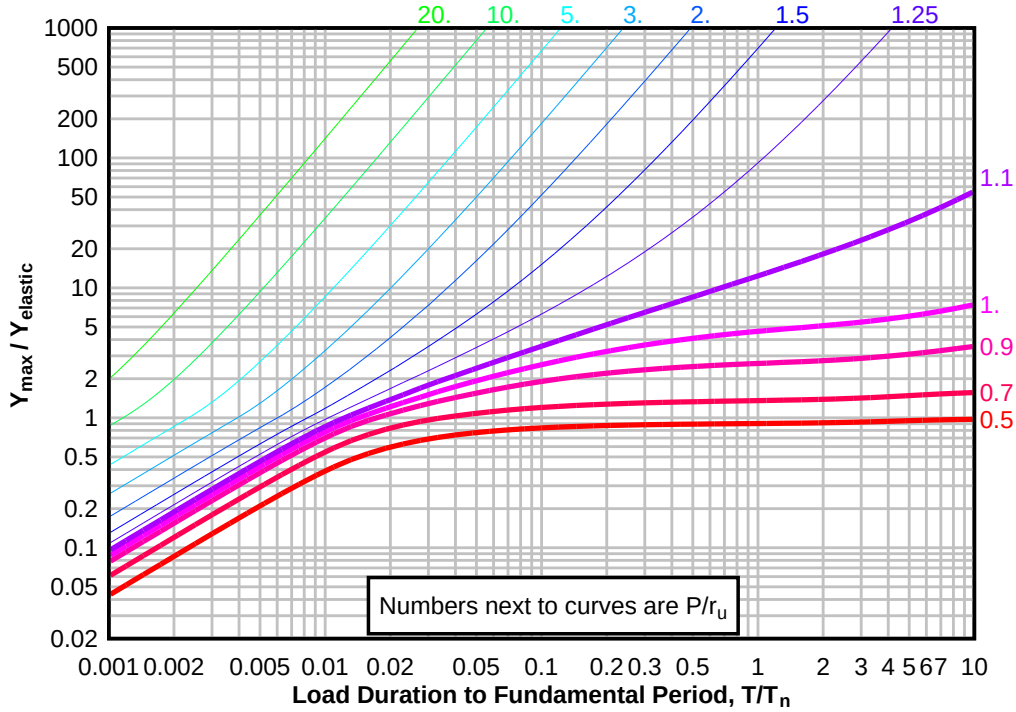


Figure 3-114(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.909, C2 = 30)

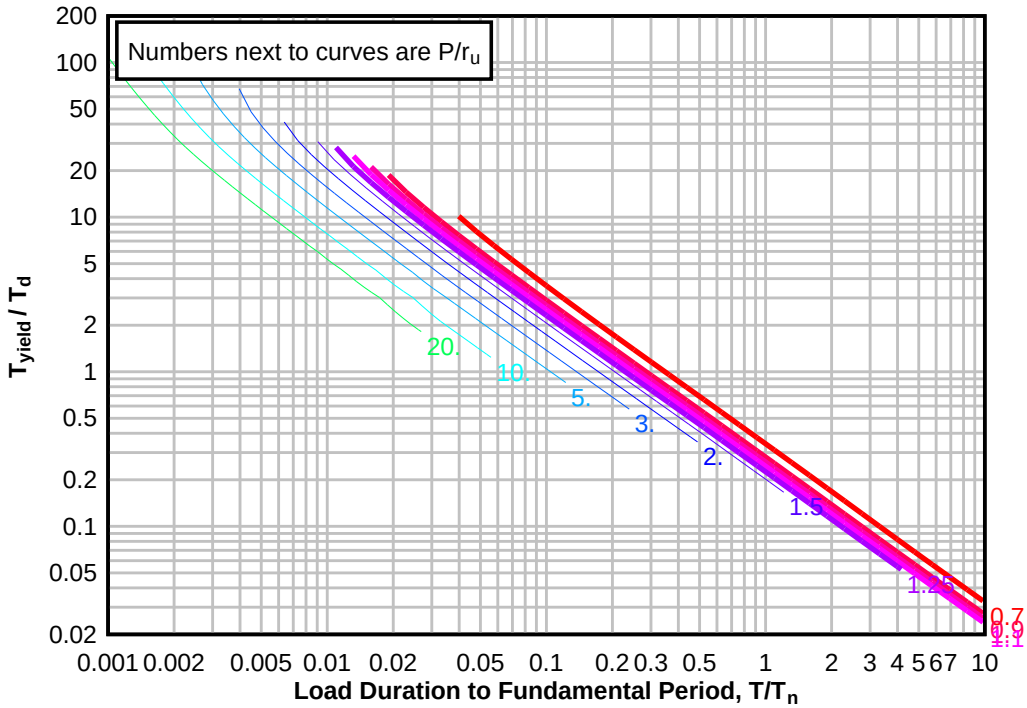


Figure 3-115(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.866, C_2 = 30)

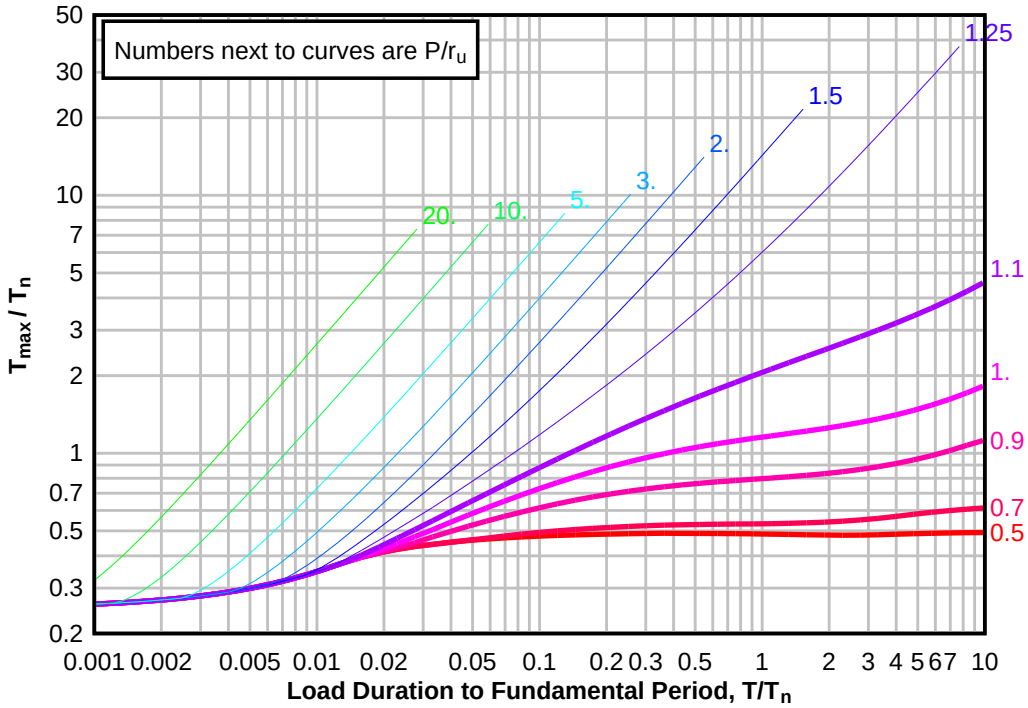


Figure 3-115(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.866, C2 = 30)

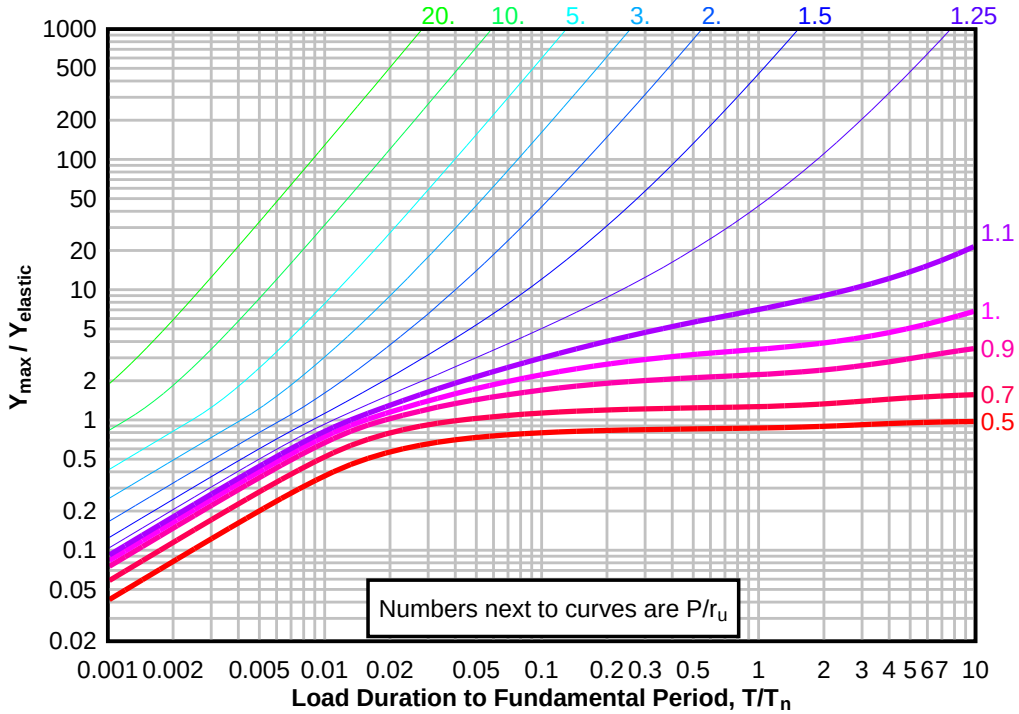


Figure 3-115(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.866, C2 = 30)

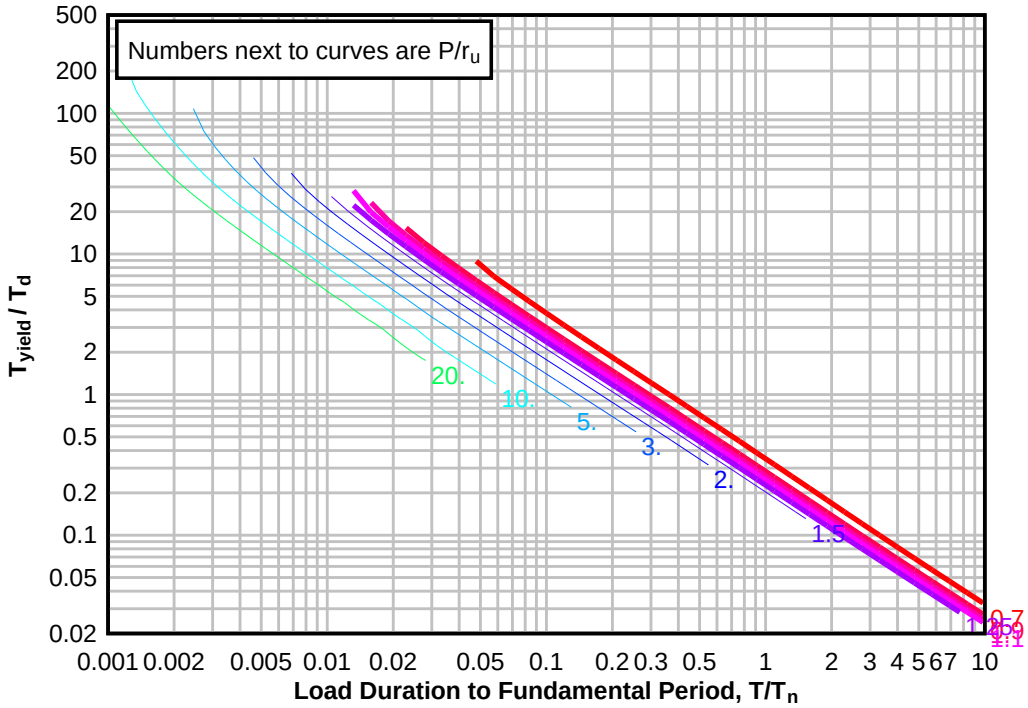


Figure 3-116(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.825, C_2 = 30)

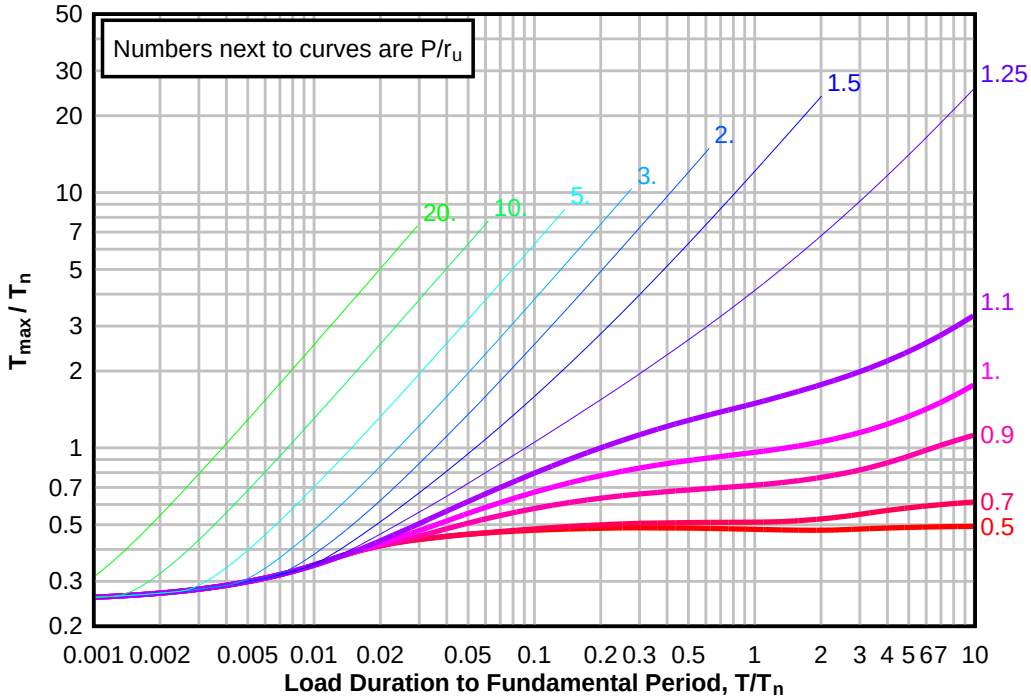


Figure 3-116(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.825, C2 = 30)

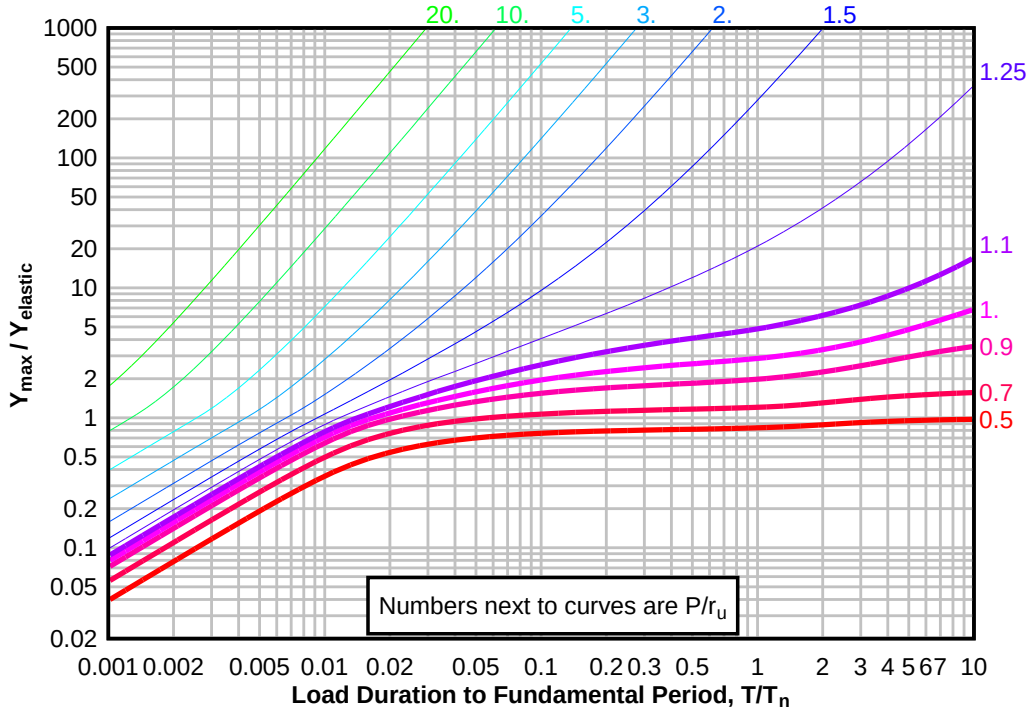


Figure 3-116(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.825, C2 = 30)

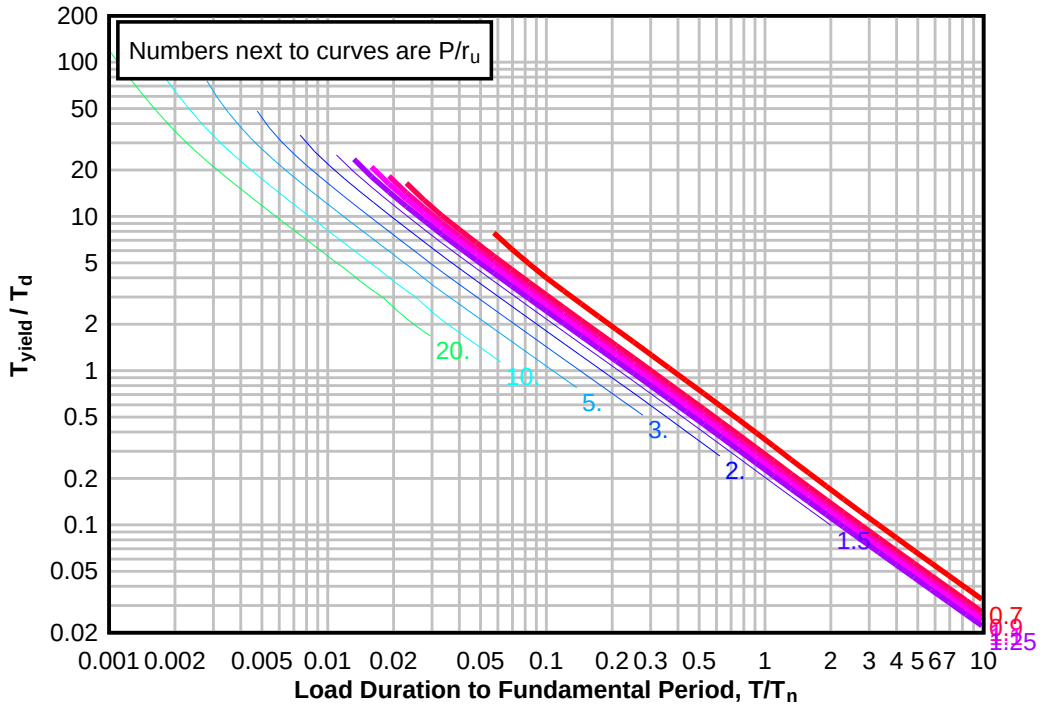


Figure 3-117(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.750, C_2 = 30)

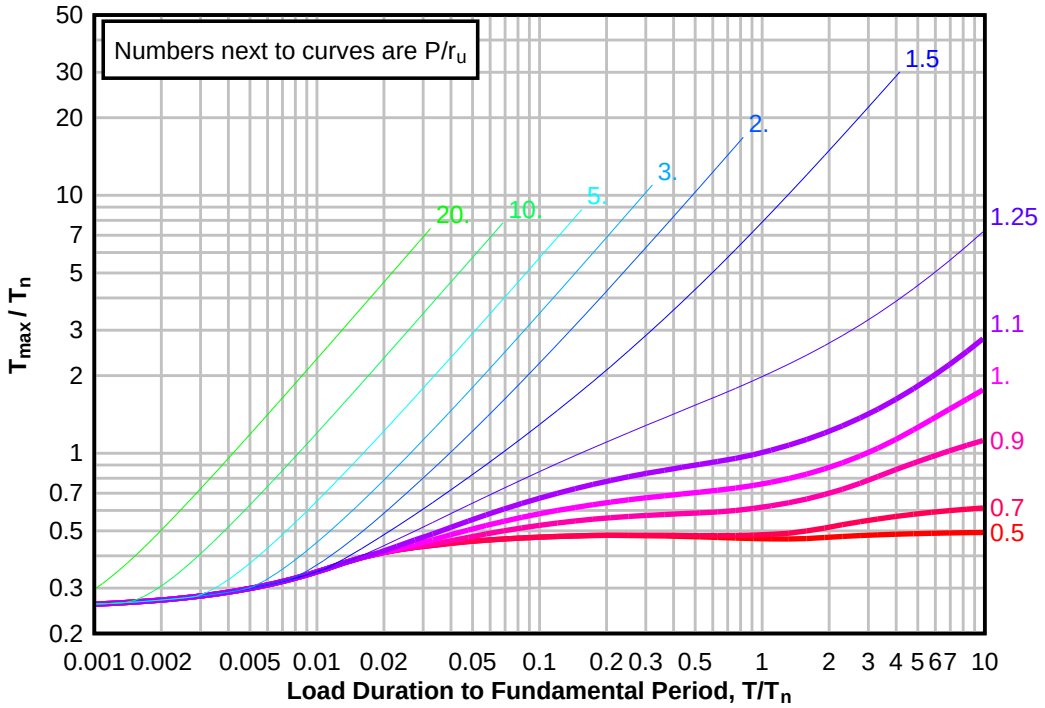


Figure 3-117(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.750, C2 = 30)

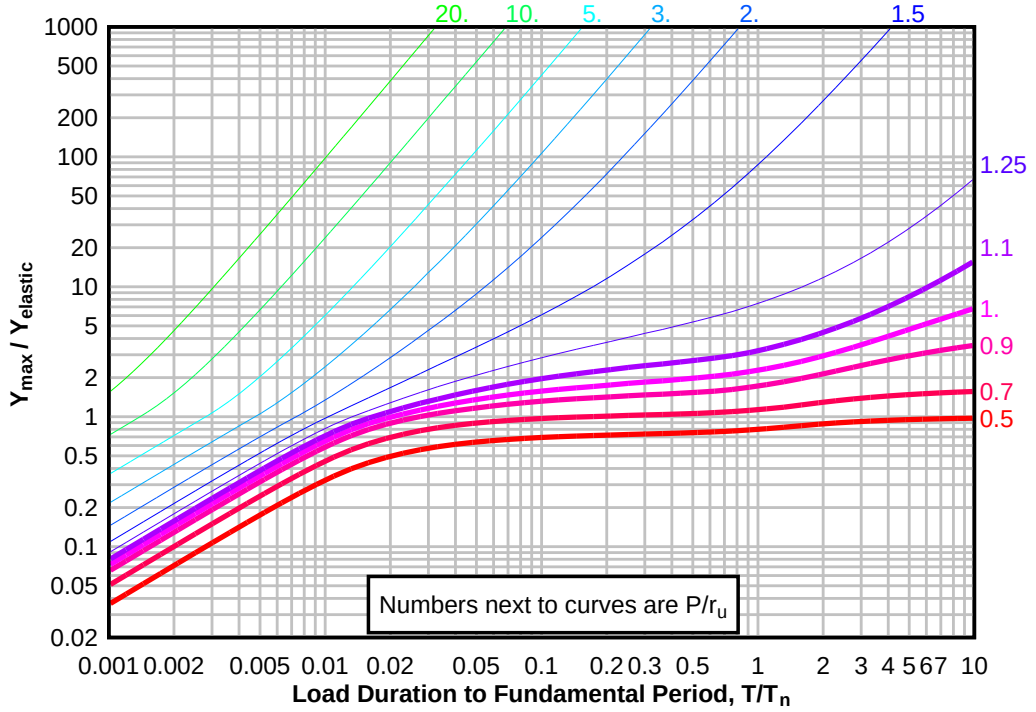


Figure 3-117(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.750, C2 = 30)

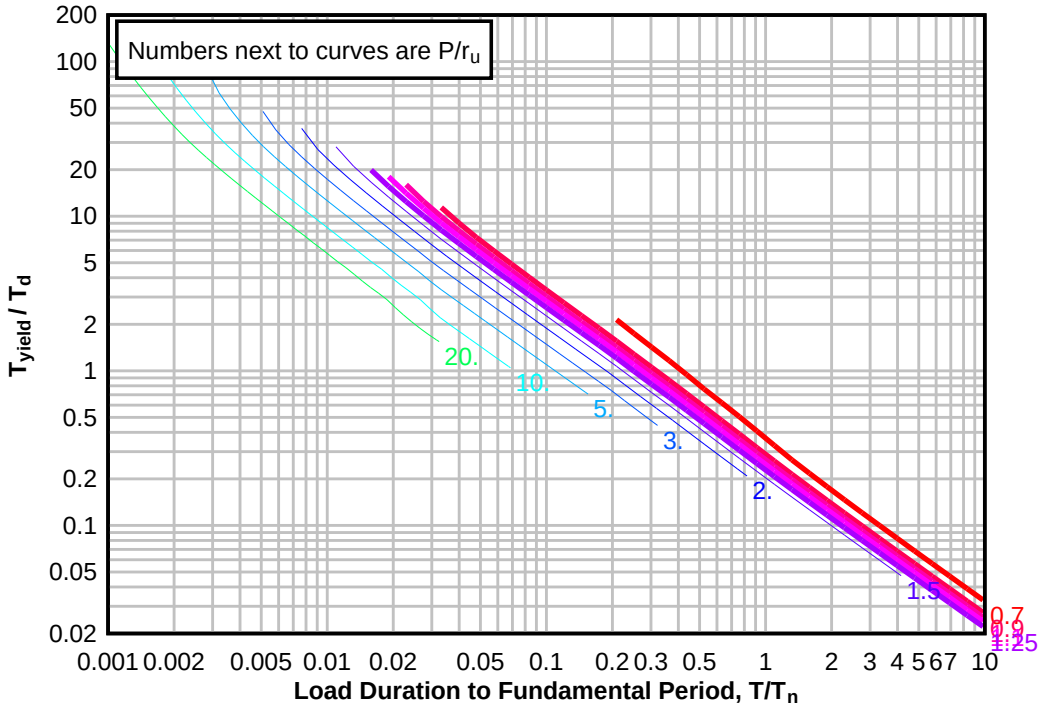


Figure 3-118(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.715, C_2 = 30)

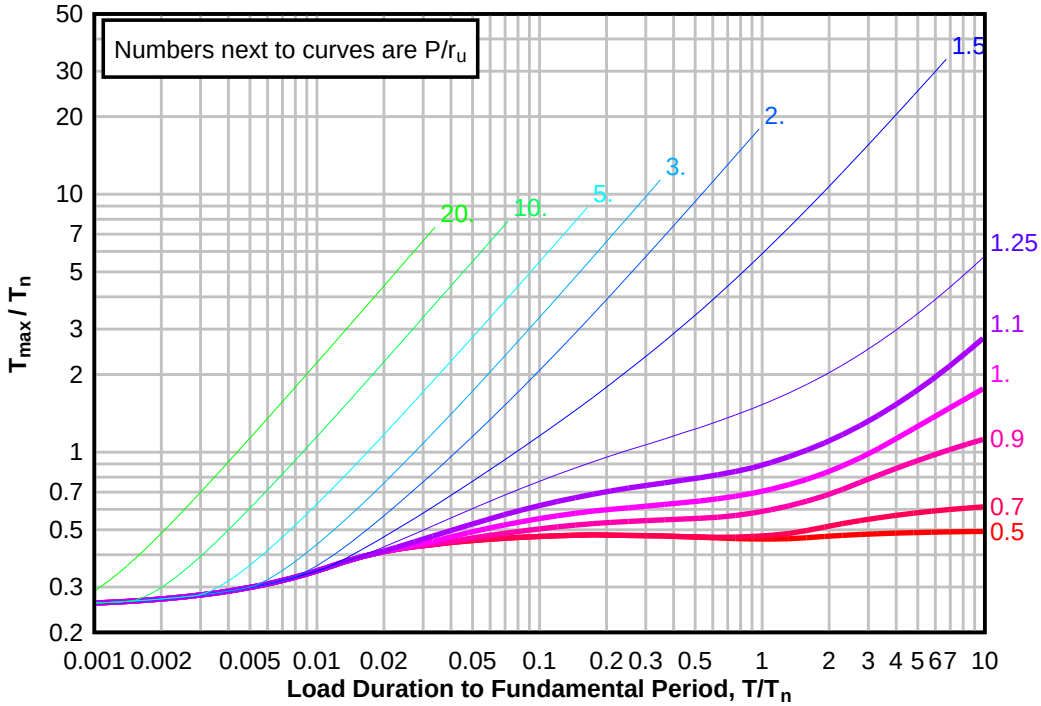


Figure 3-118(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.715, C2 = 30)

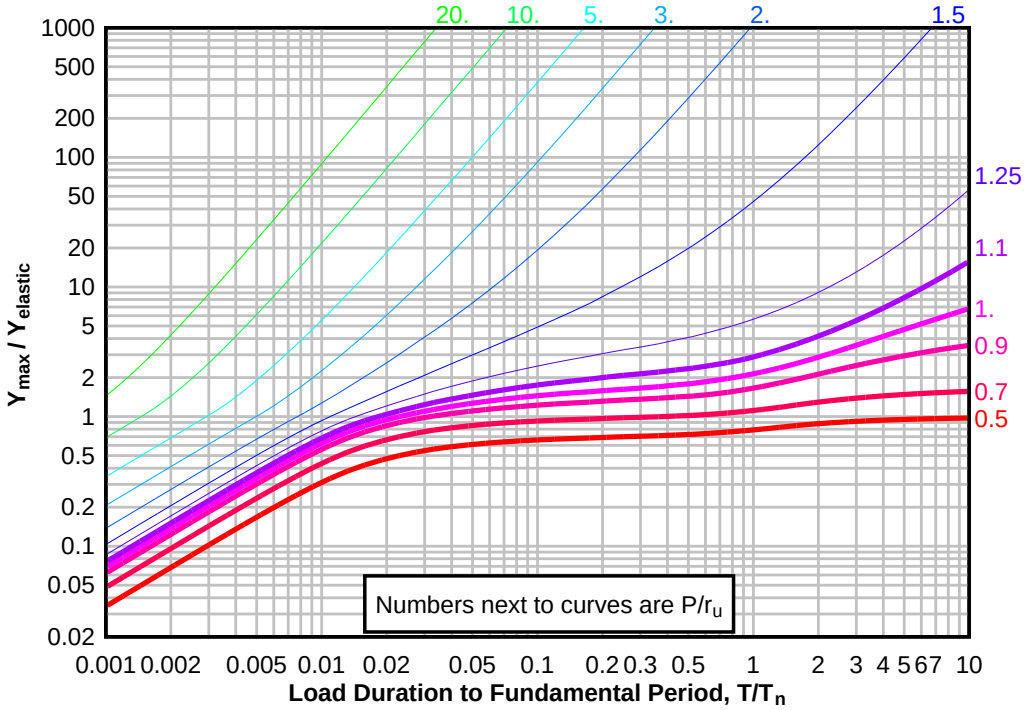


Figure 3-118(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.715, C2 = 30)

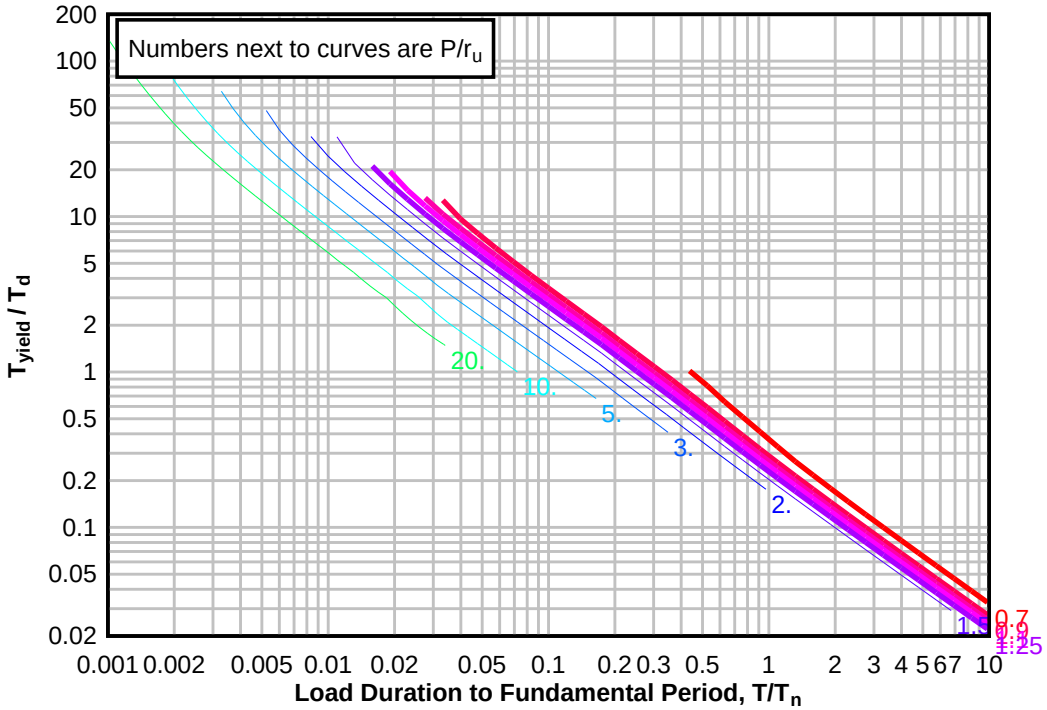


Figure 3-119(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.681, C_2 = 30)

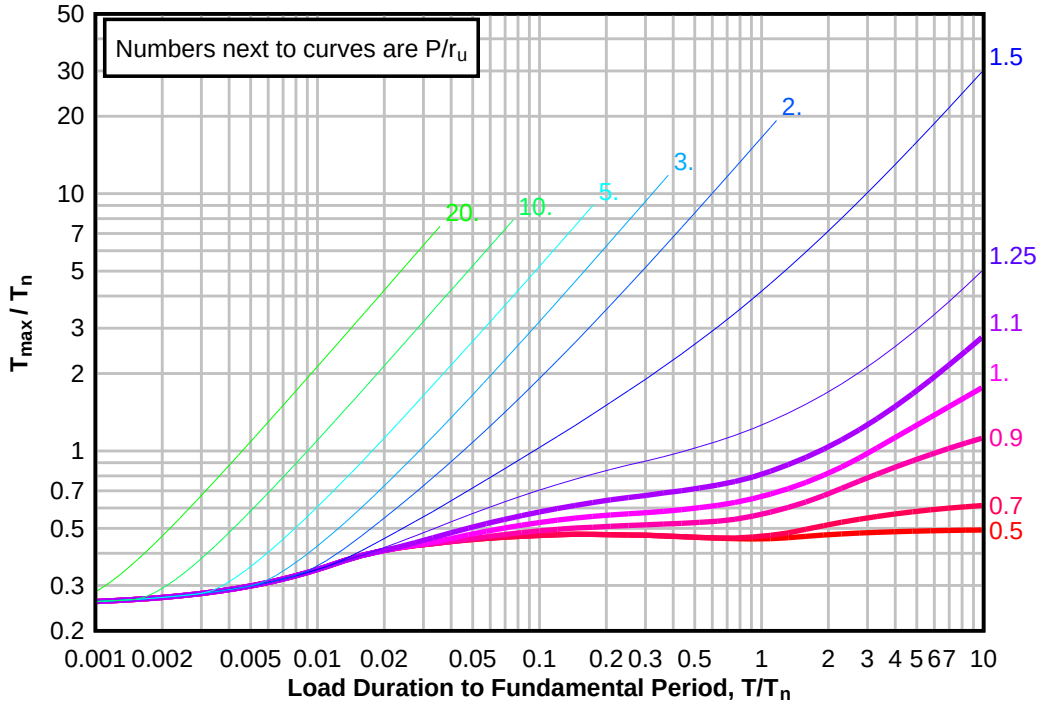


Figure 3-119(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.681, C2 = 30)

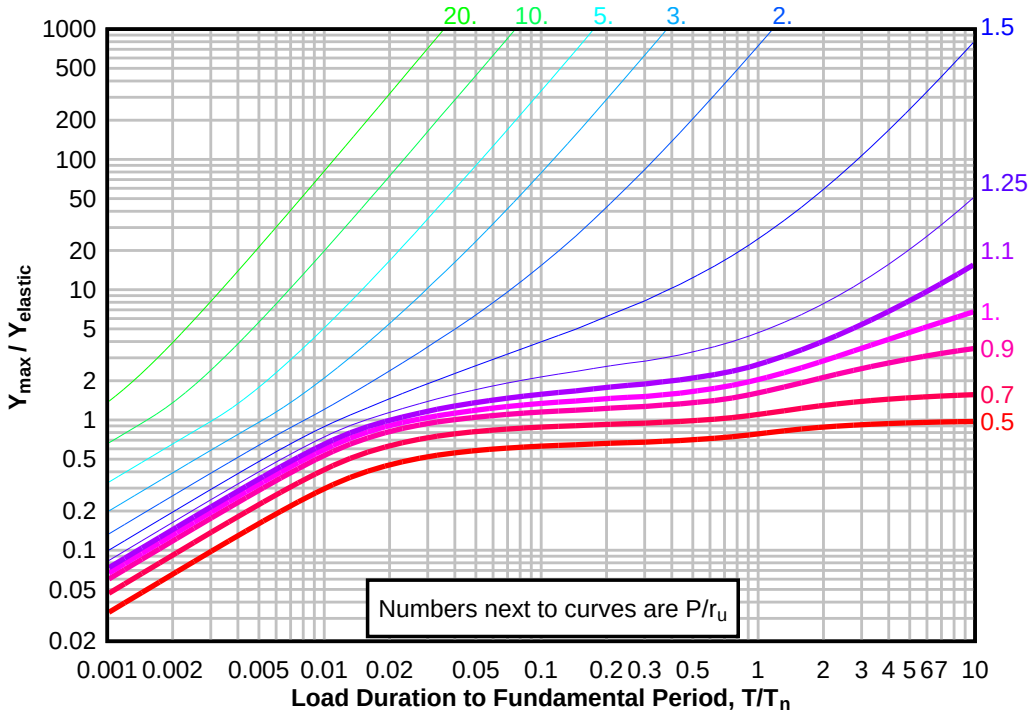


Figure 3-119(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.681, C2 = 30)

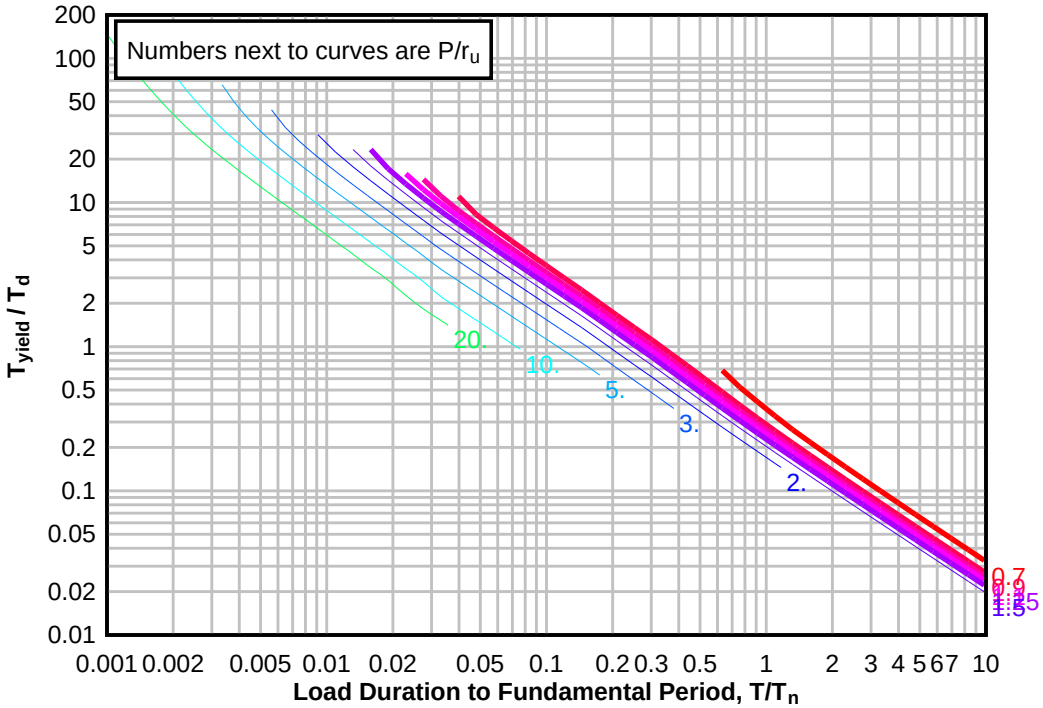


Figure 3-120(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.648, C_2 = 30)

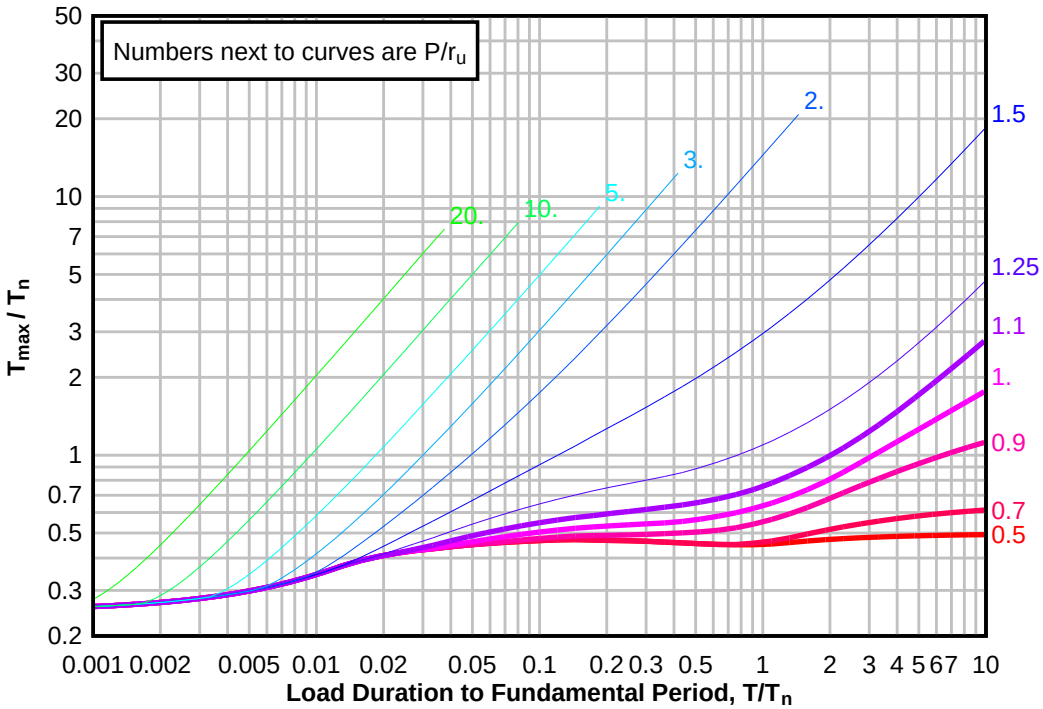


Figure 3-120(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.648, C2 = 30)

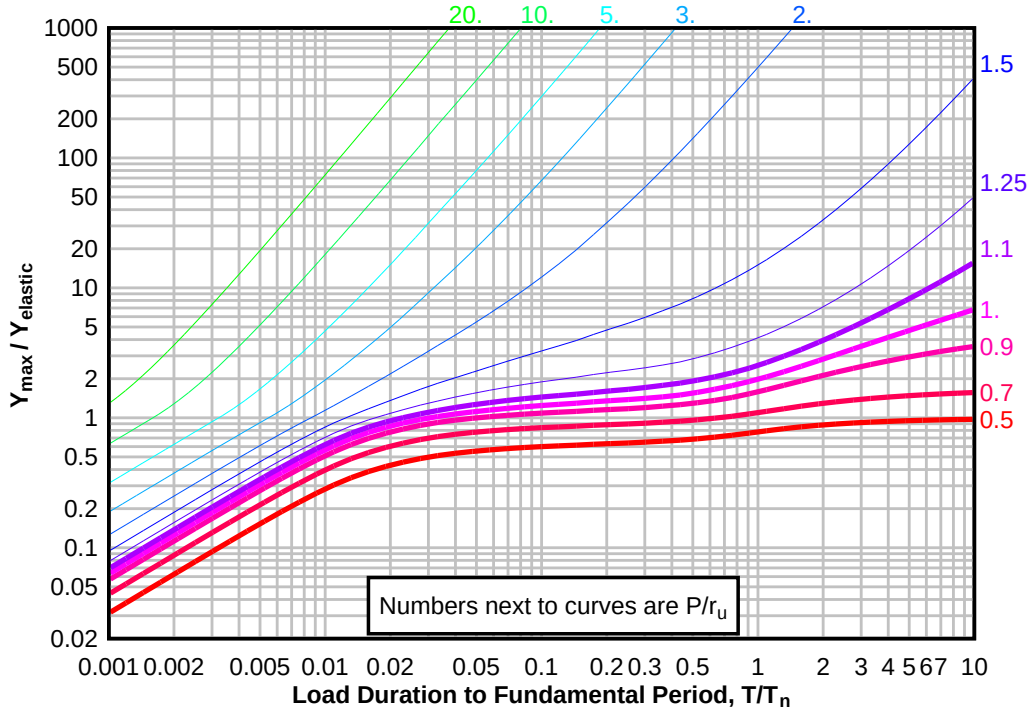


Figure 3-120(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.648, C2 = 30)

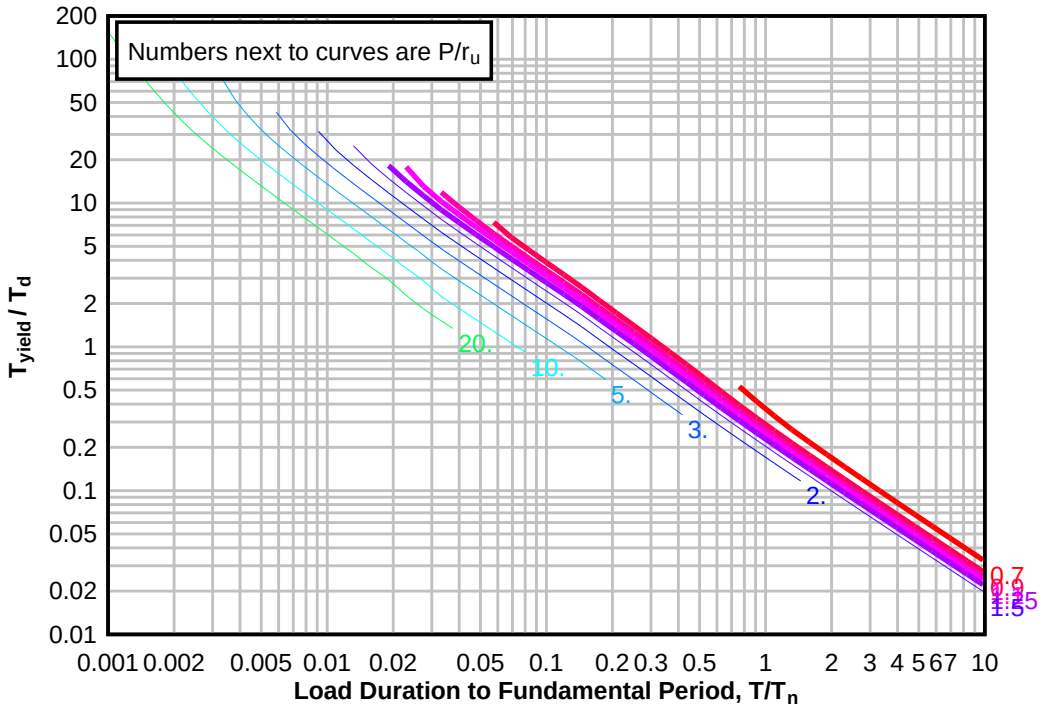


Figure 3-121(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.619, C_2 = 30)

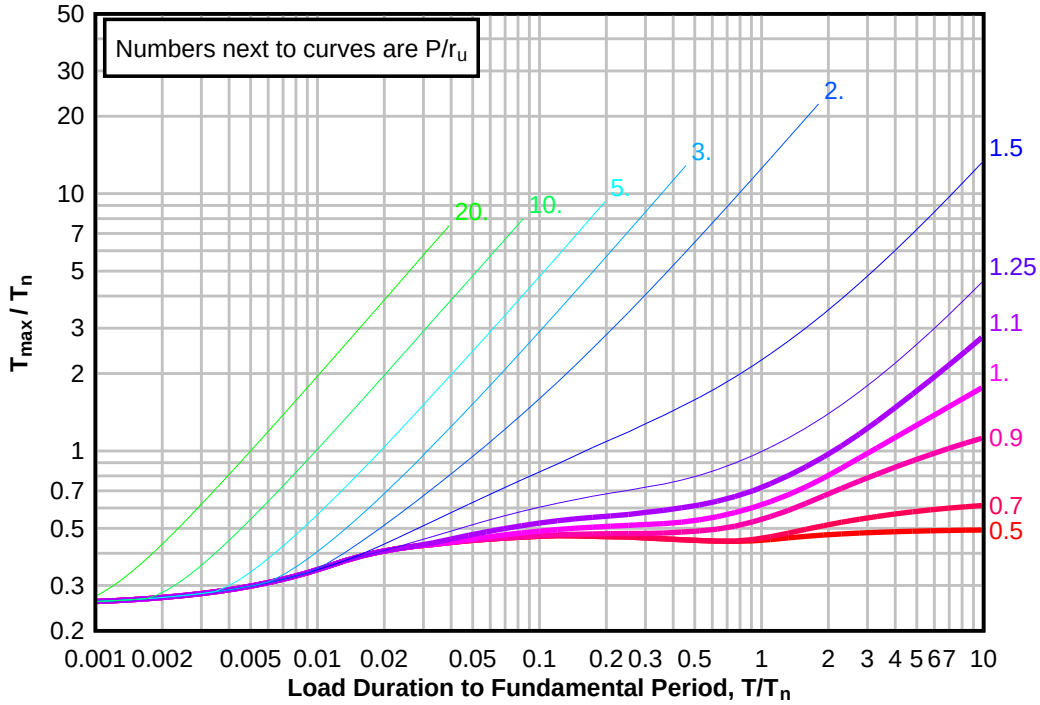


Figure 3-121(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.619, C2 = 30)

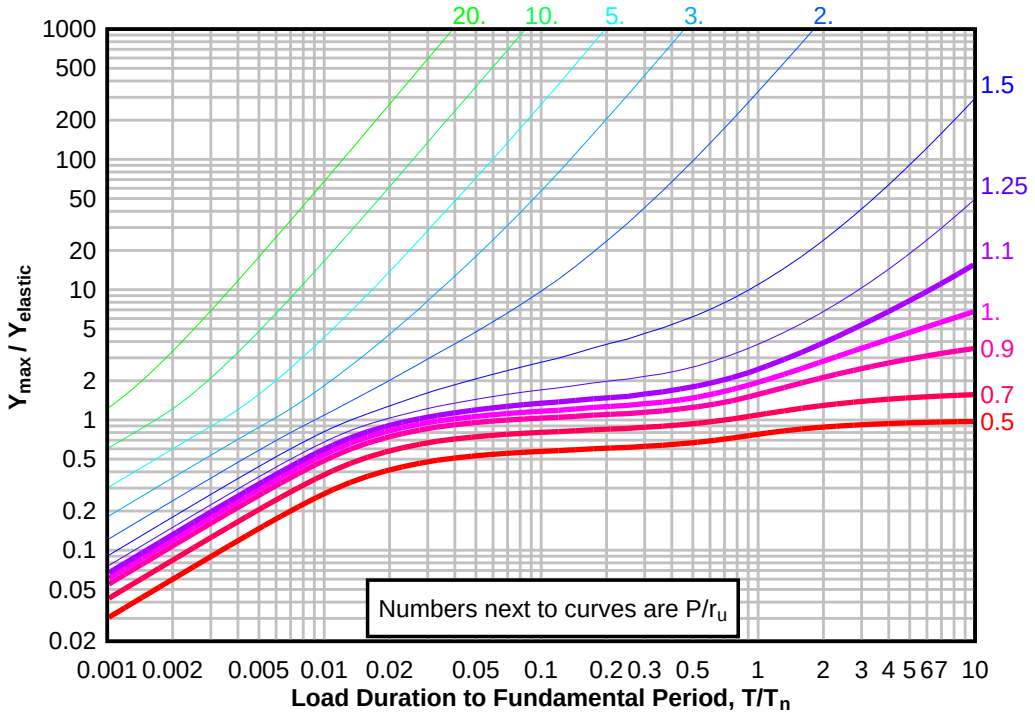


Figure 3-121(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.619, C2 = 30)

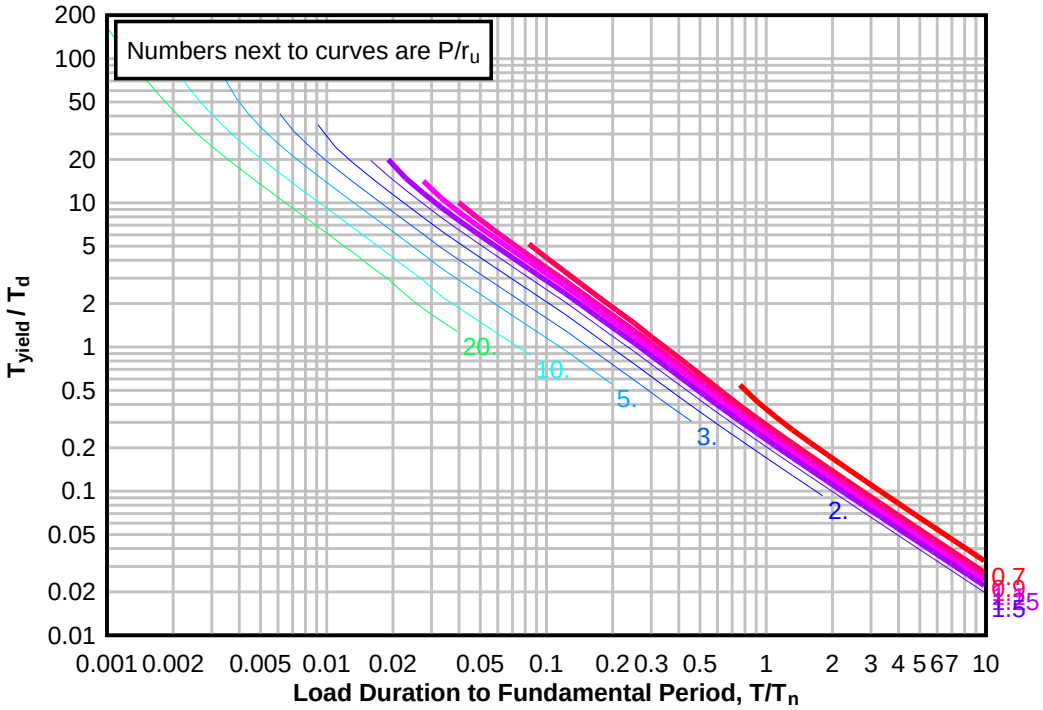


Figure 3-122(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.562, C_2 = 30)

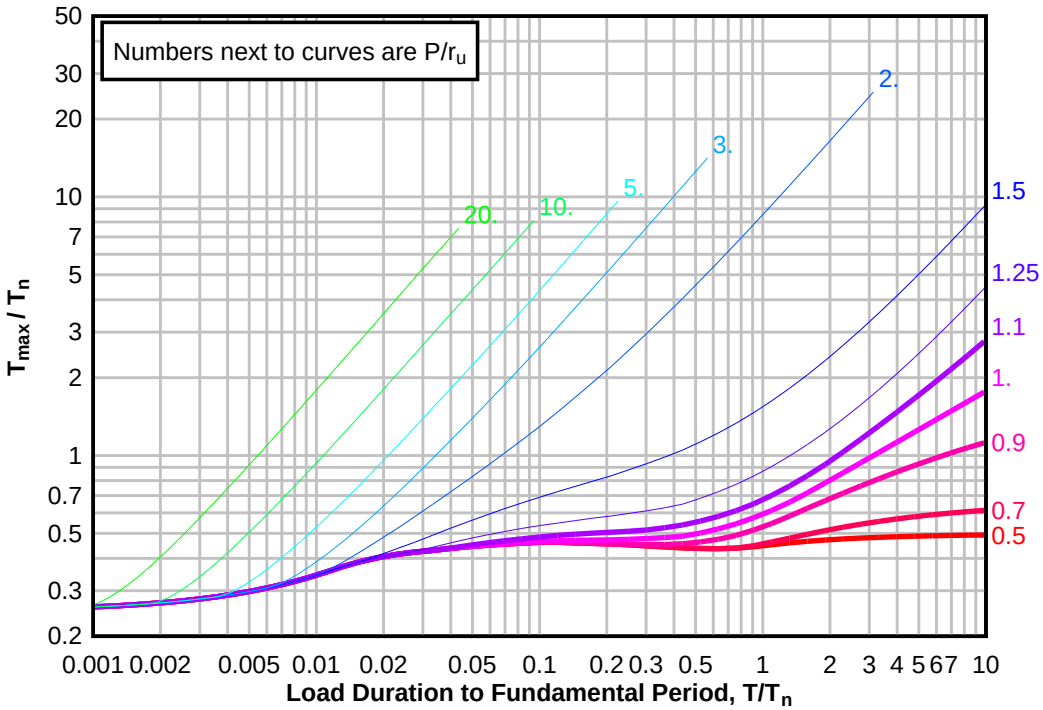


Figure 3-122(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.562, C2 = 30)

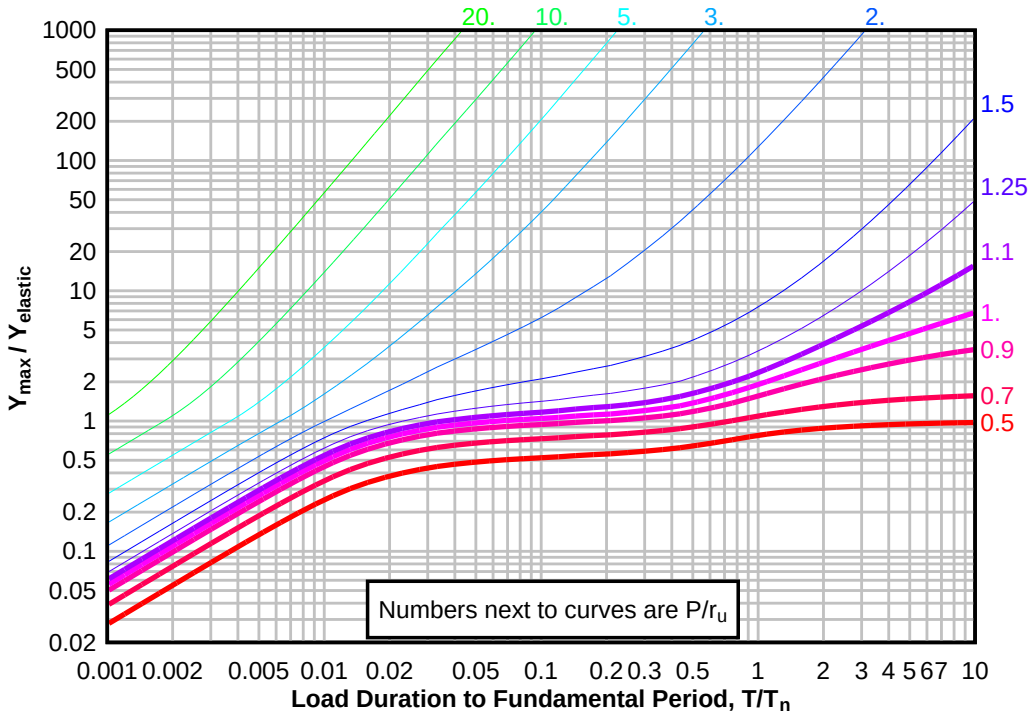


Figure 3-122(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.562, C2 = 30)

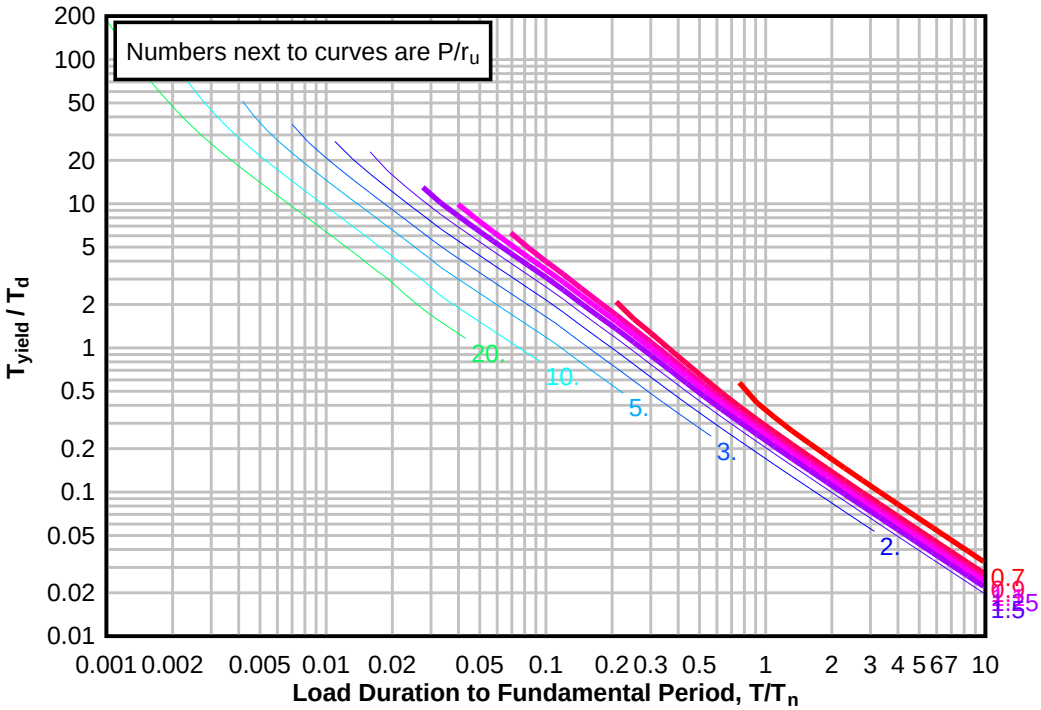


Figure 3-123(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.511, C_2 = 30)

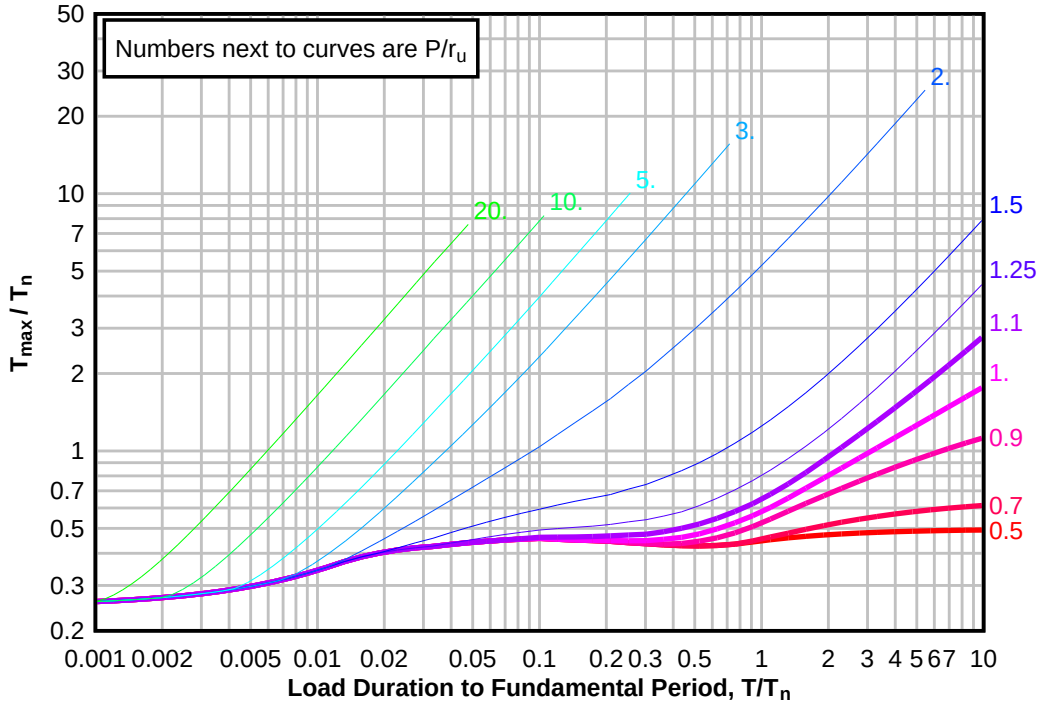


Figure 3-123(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.511, C2 = 30)

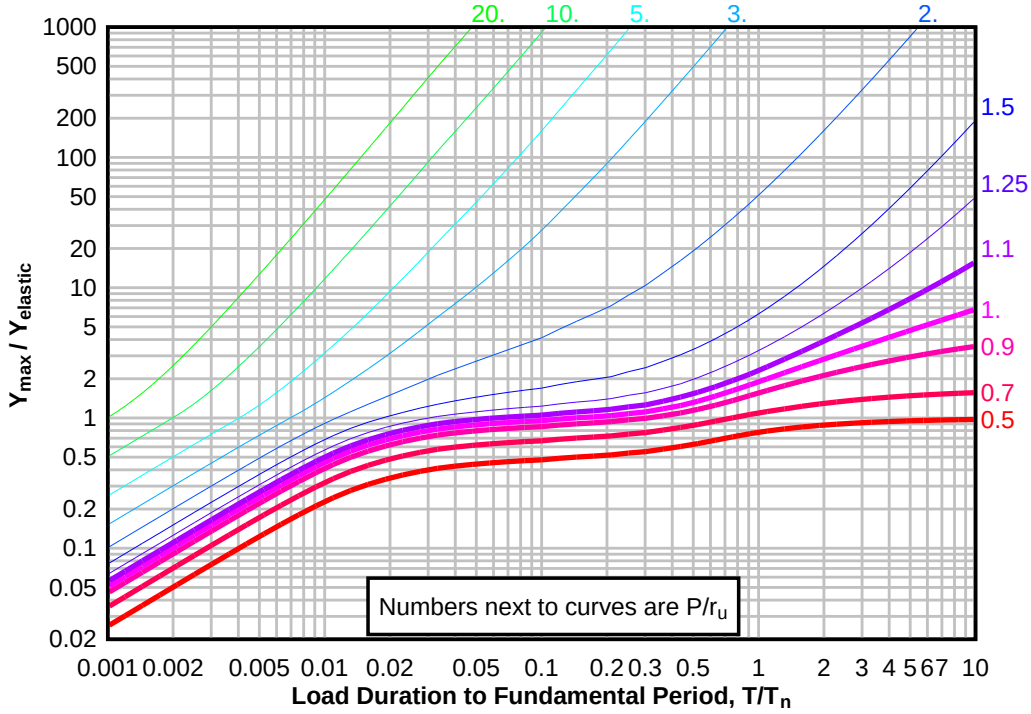


Figure 3-123(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.511, C2 = 30)

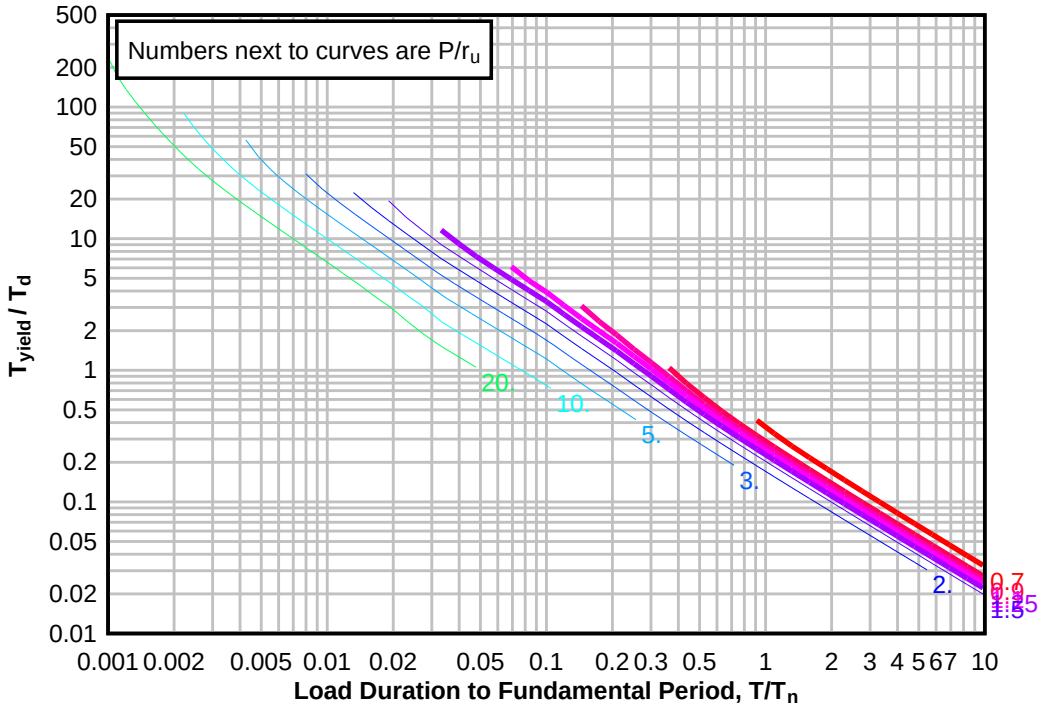


Figure 3-124(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.464, C_2 = 30)

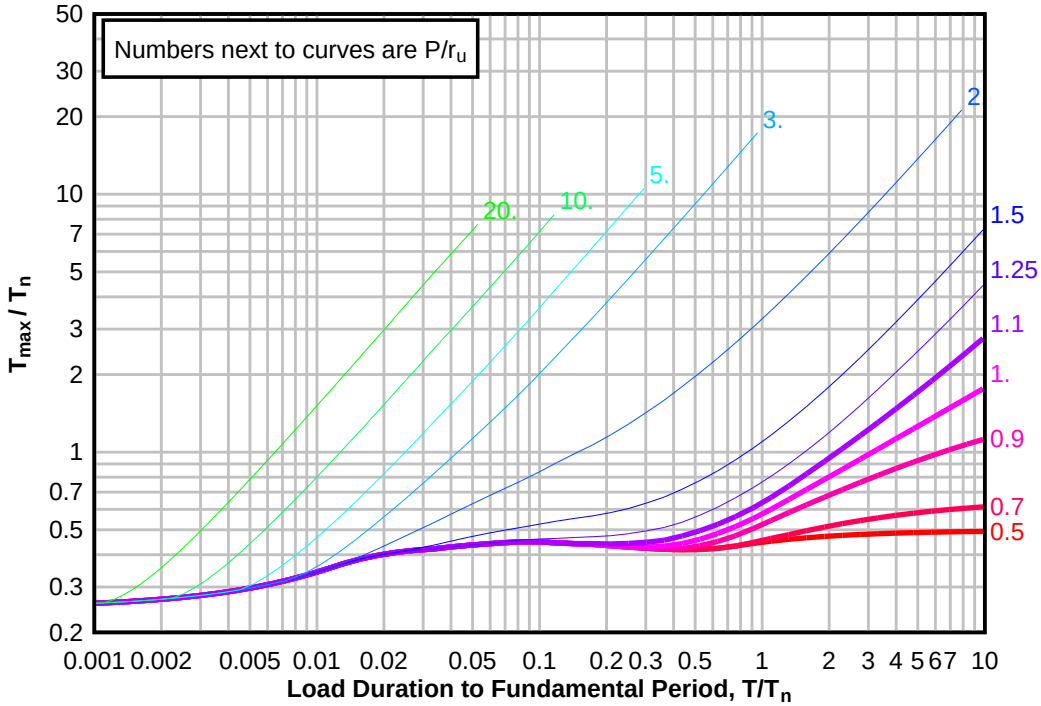


Figure 3-124(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.464, C2 = 30)

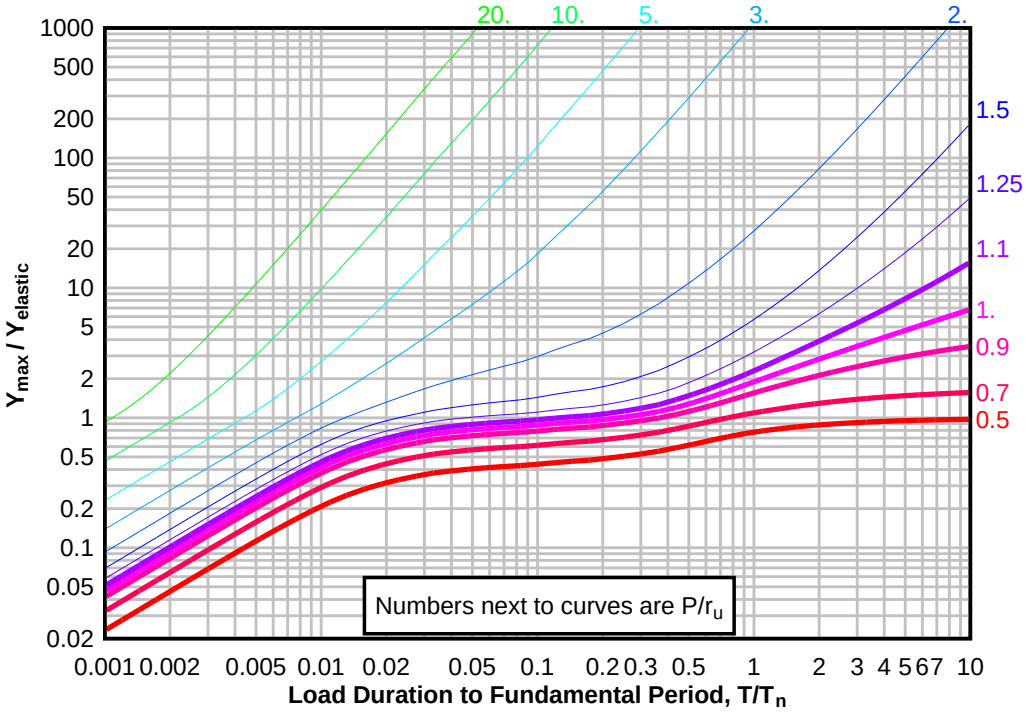


Figure 3-124(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.464, C2 = 30)

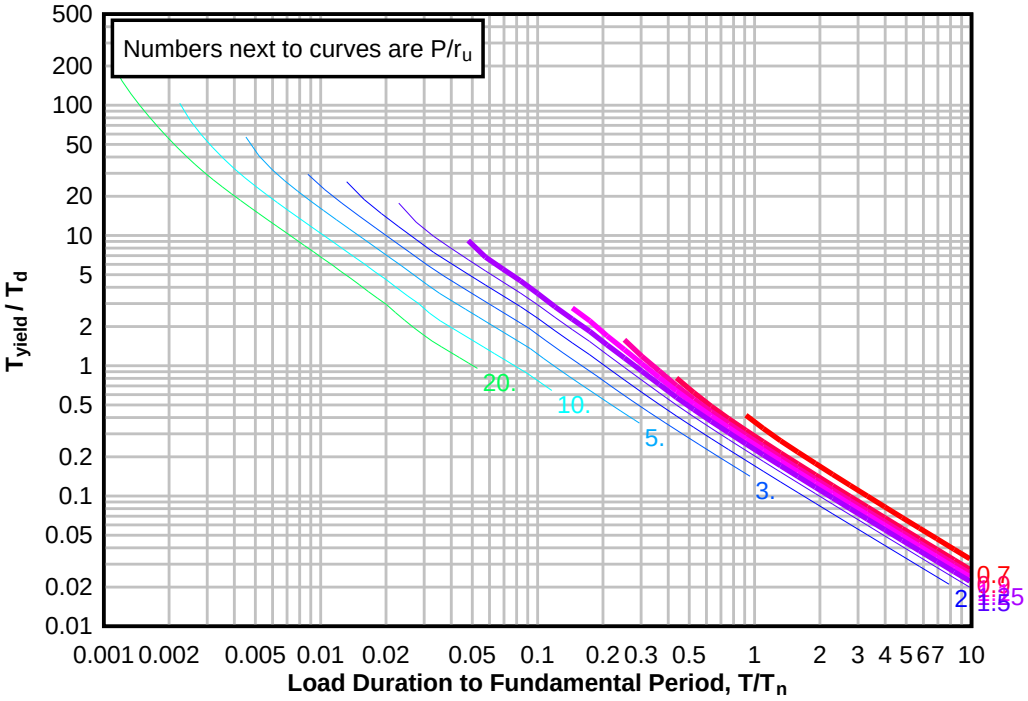


Figure 3-125(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.383, C_2 = 30)

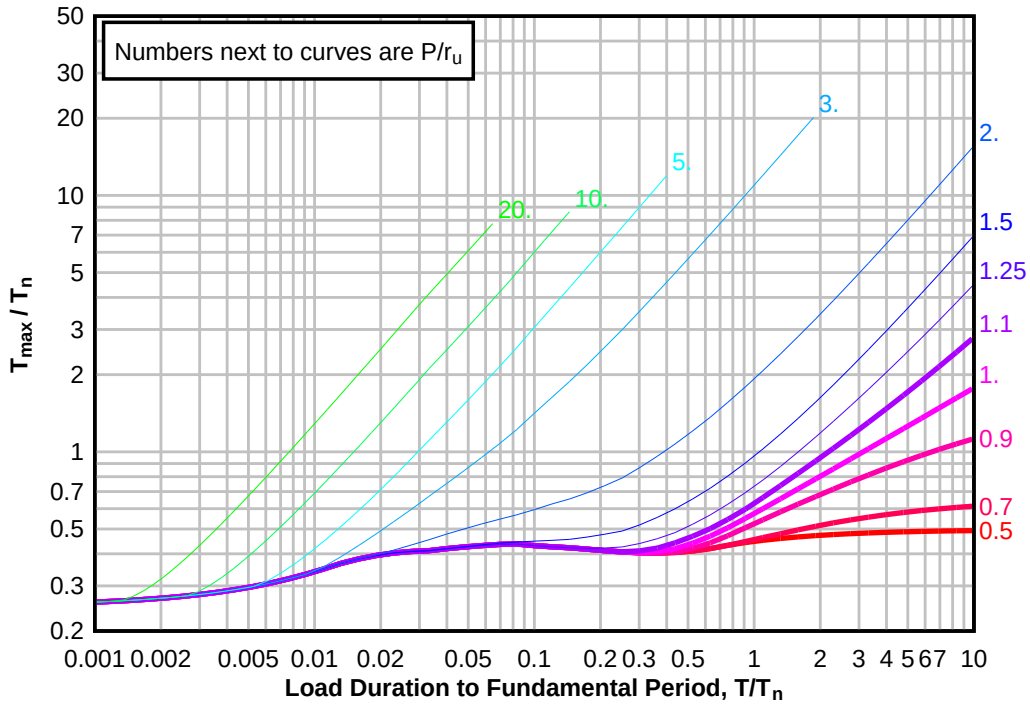


Figure 3-125(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.383, C2 = 30)

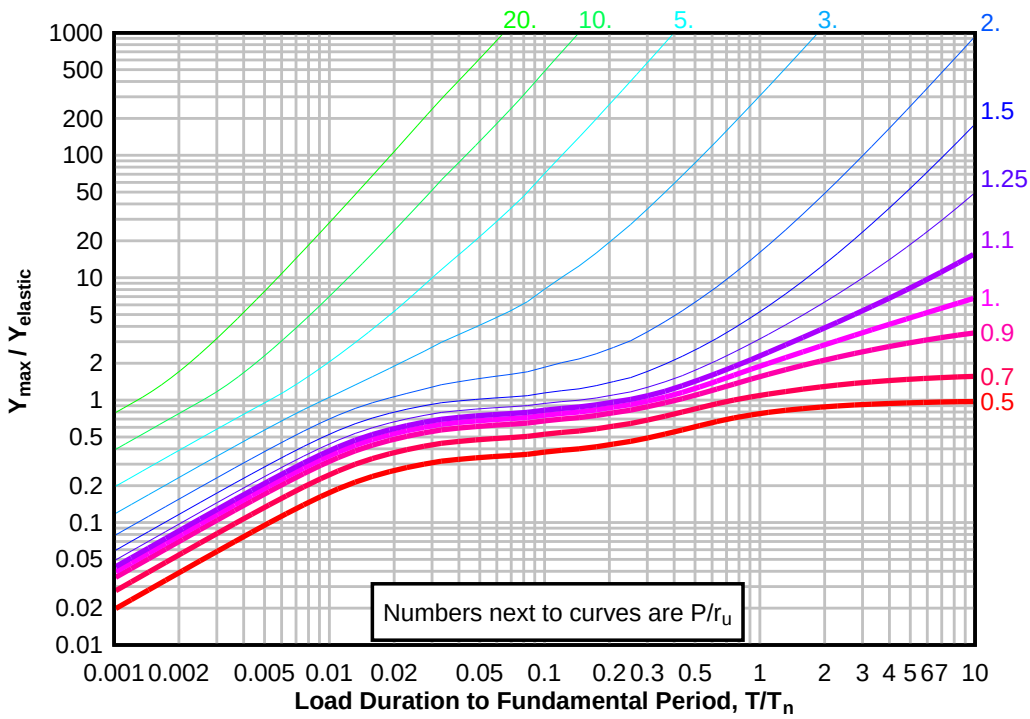


Figure 3-125(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.383, C2 = 30)

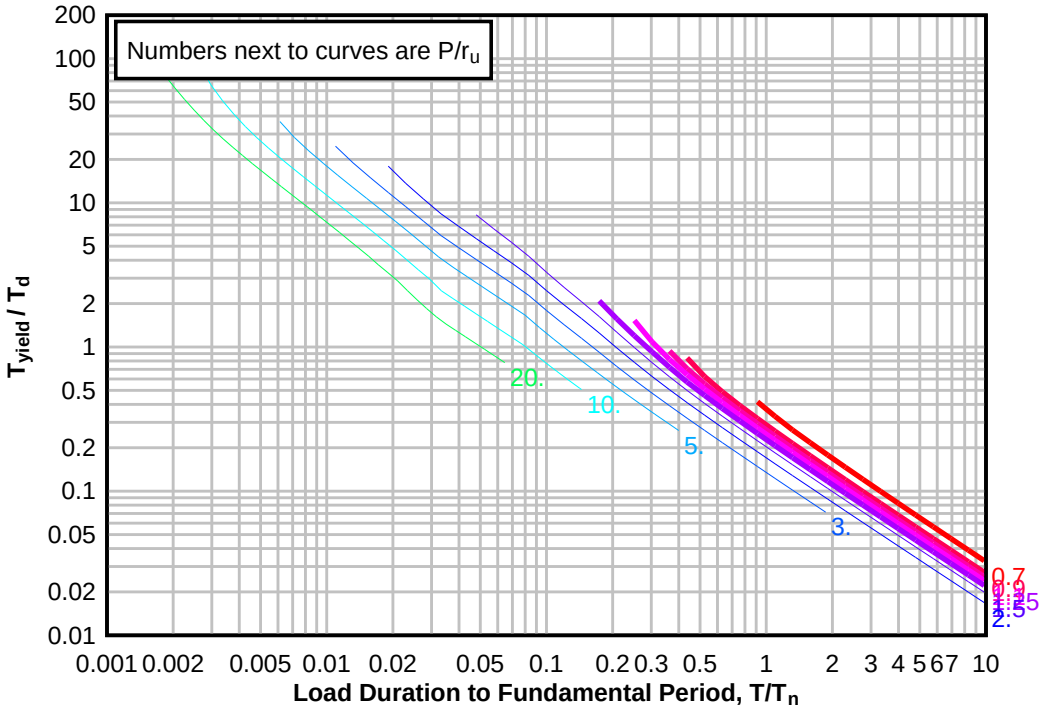


Figure 3-126(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.316, C_2 = 30)

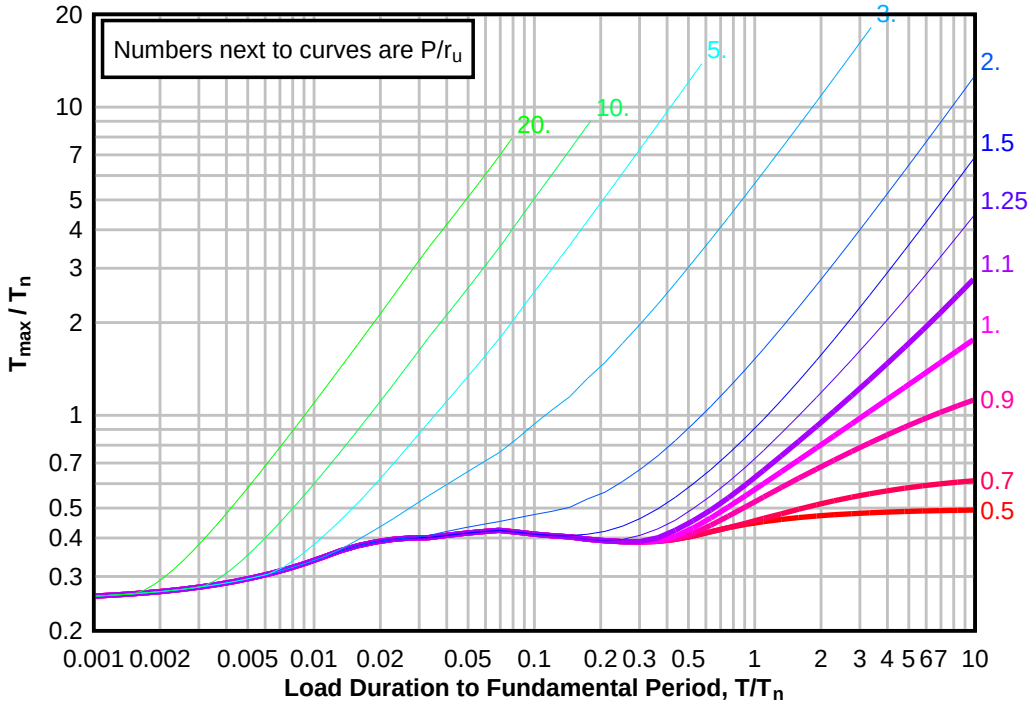


Figure 3-126(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.316, C2 = 30)

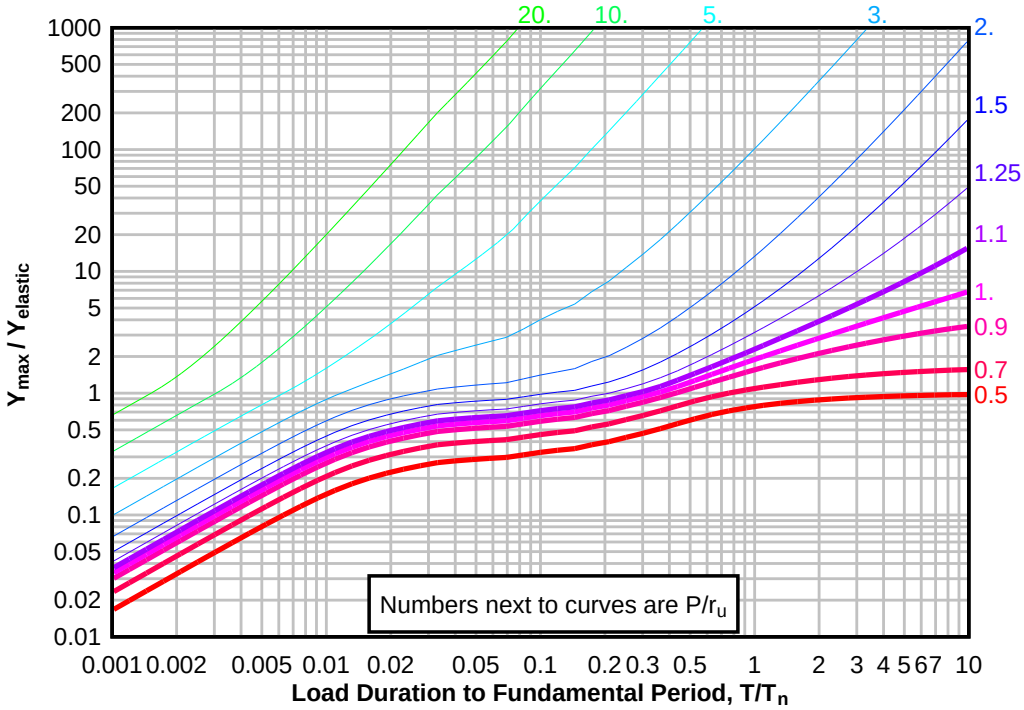


Figure 3-126(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.316, C2 = 30)

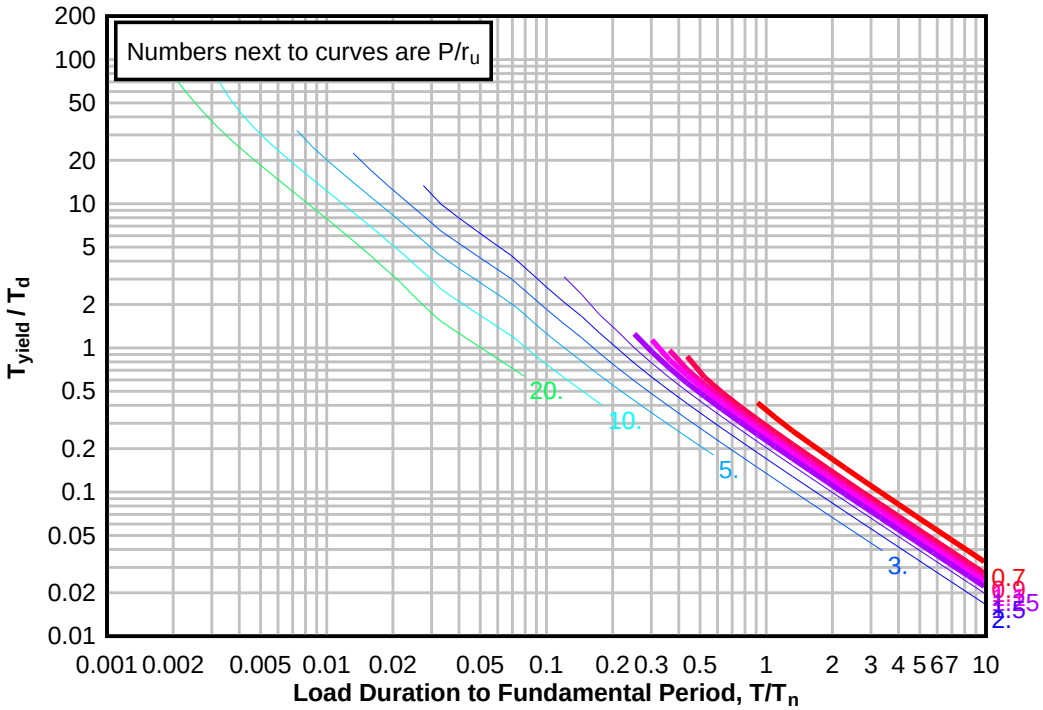


Figure 3-127(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.261, C_2 = 30)

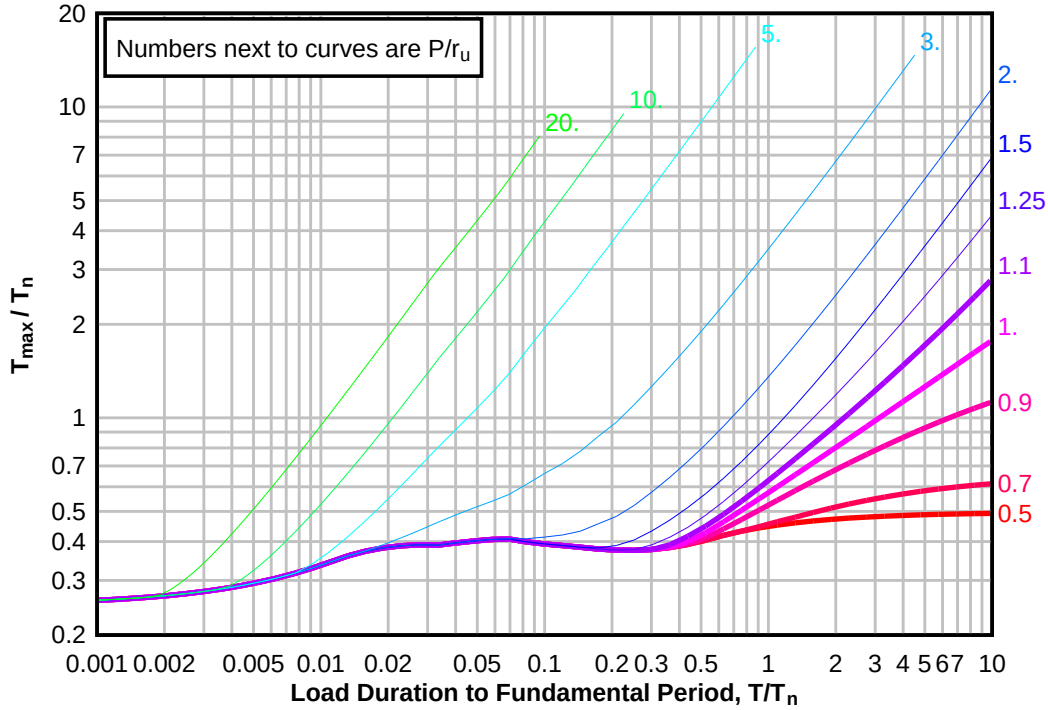


Figure 3-127 (b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.261, C2 = 30)

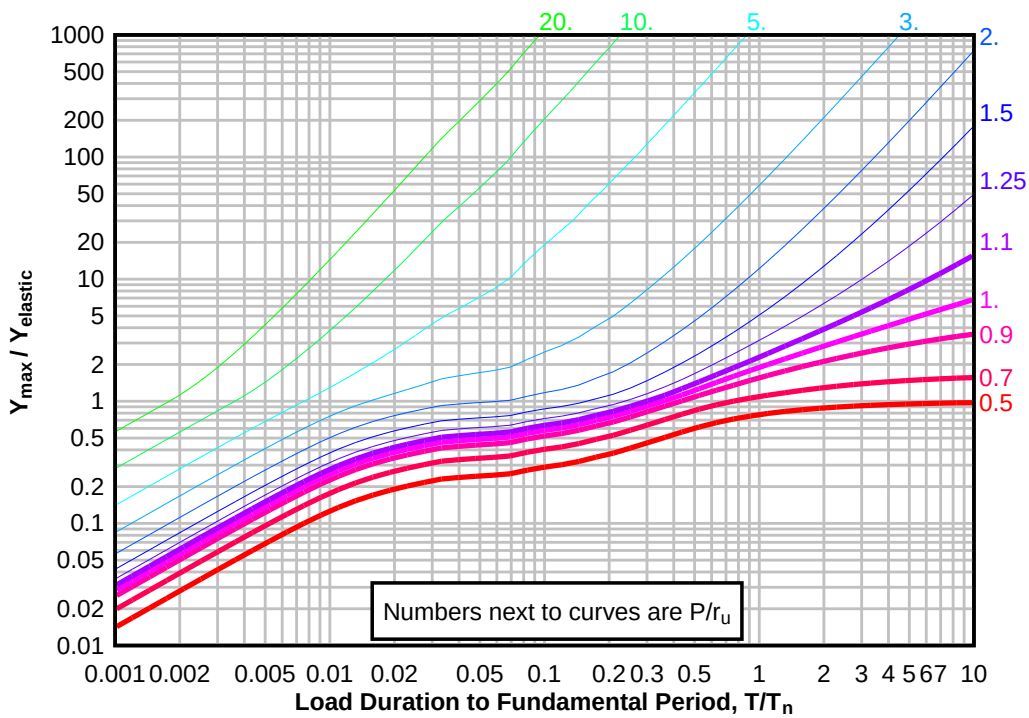


Figure 3-127(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.261, C2 = 30)

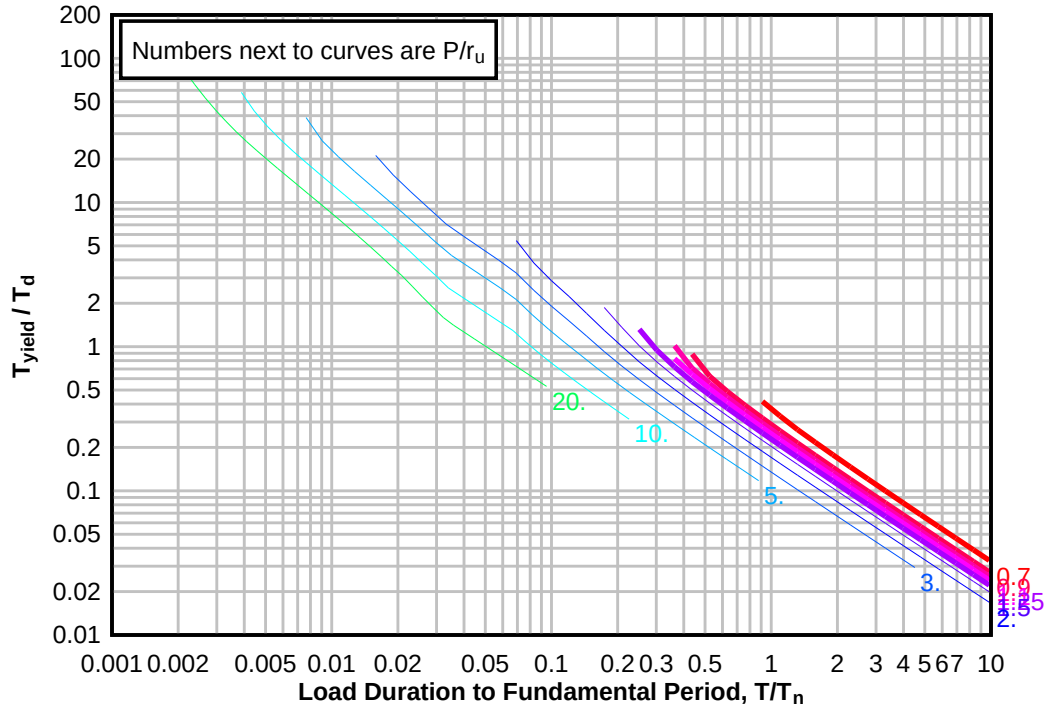


Figure 3-128 (a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.215, C_2 = 30)

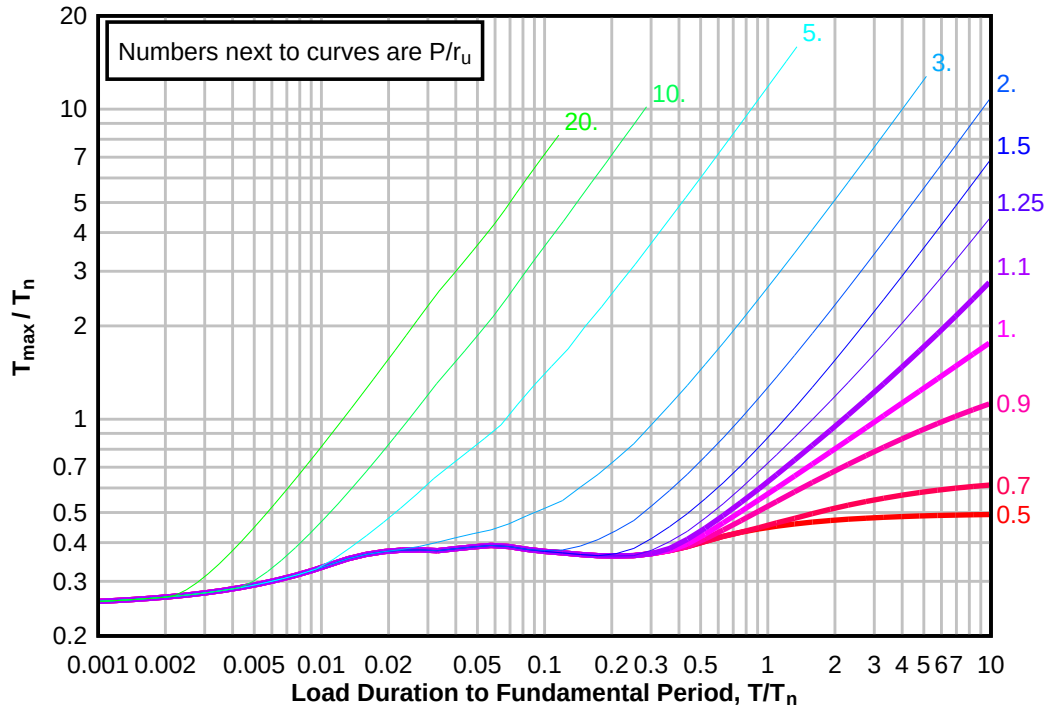


Figure 3-128 (b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.215, C2 = 30)

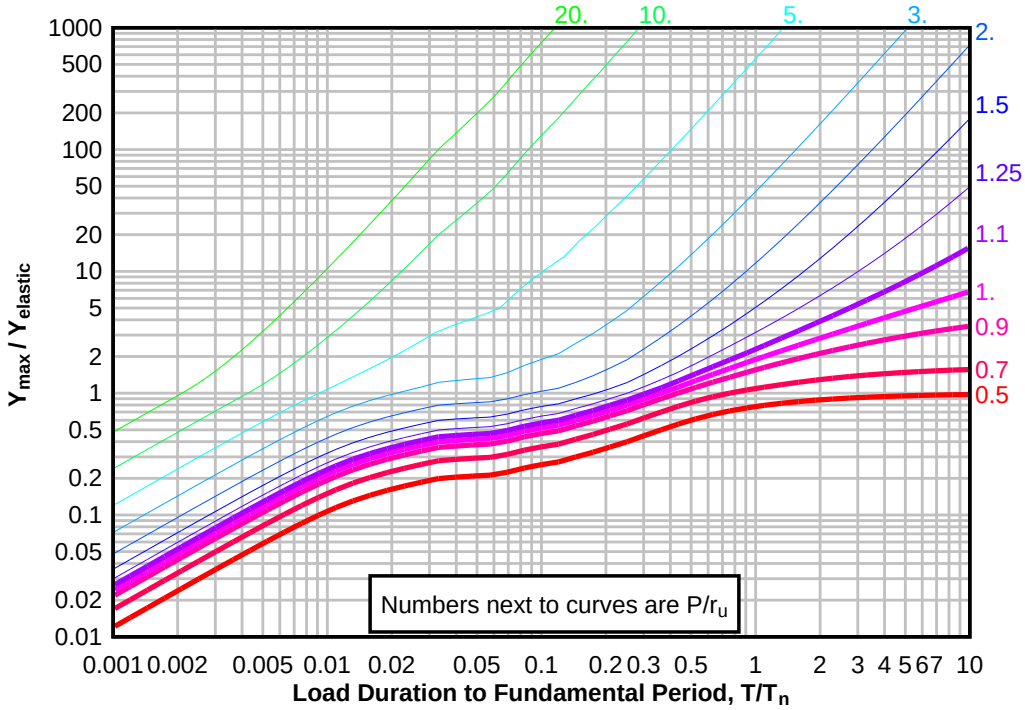


Figure 3-128(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.215, C2 = 30)

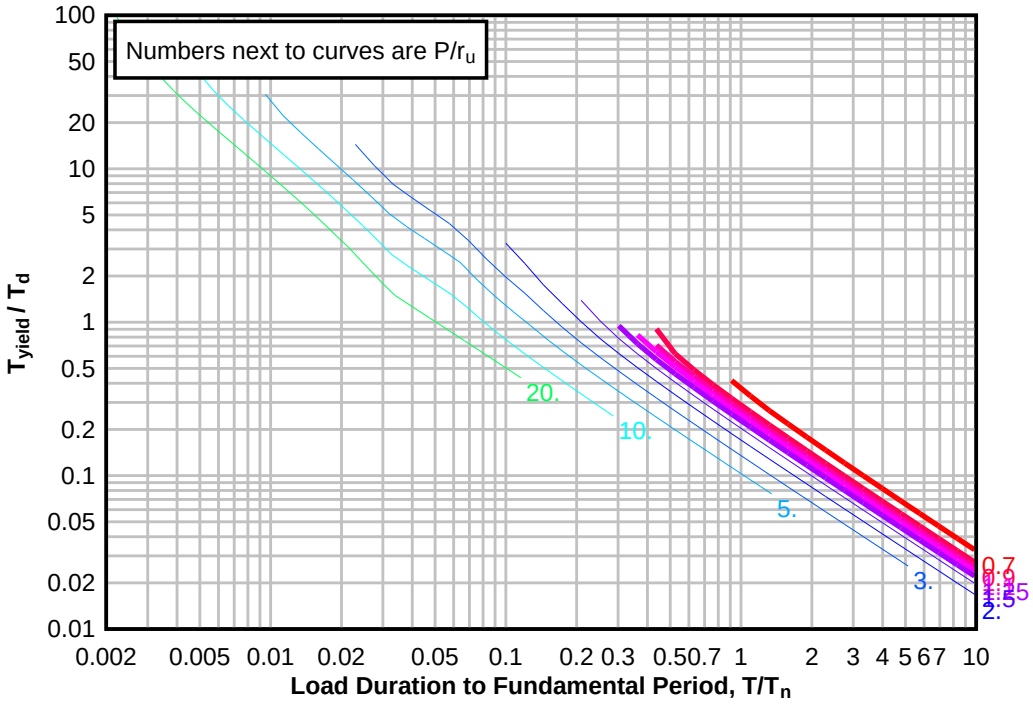


Figure 3-129 (a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.178, C_2 = 30)

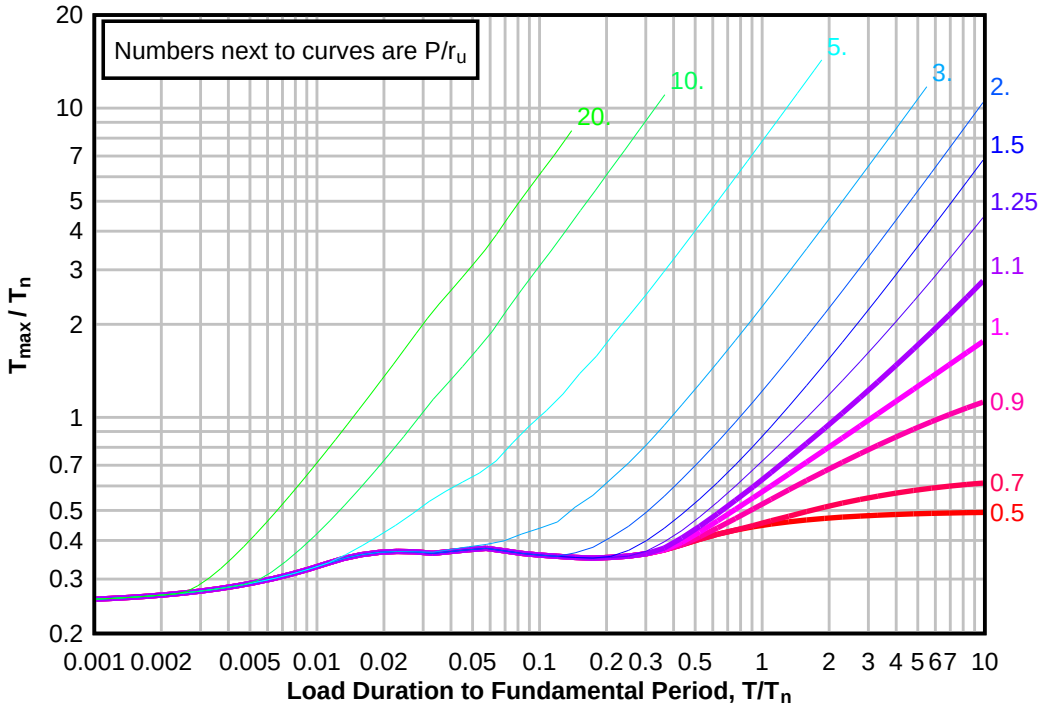


Figure 3-129 (b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.178, C2 = 30)

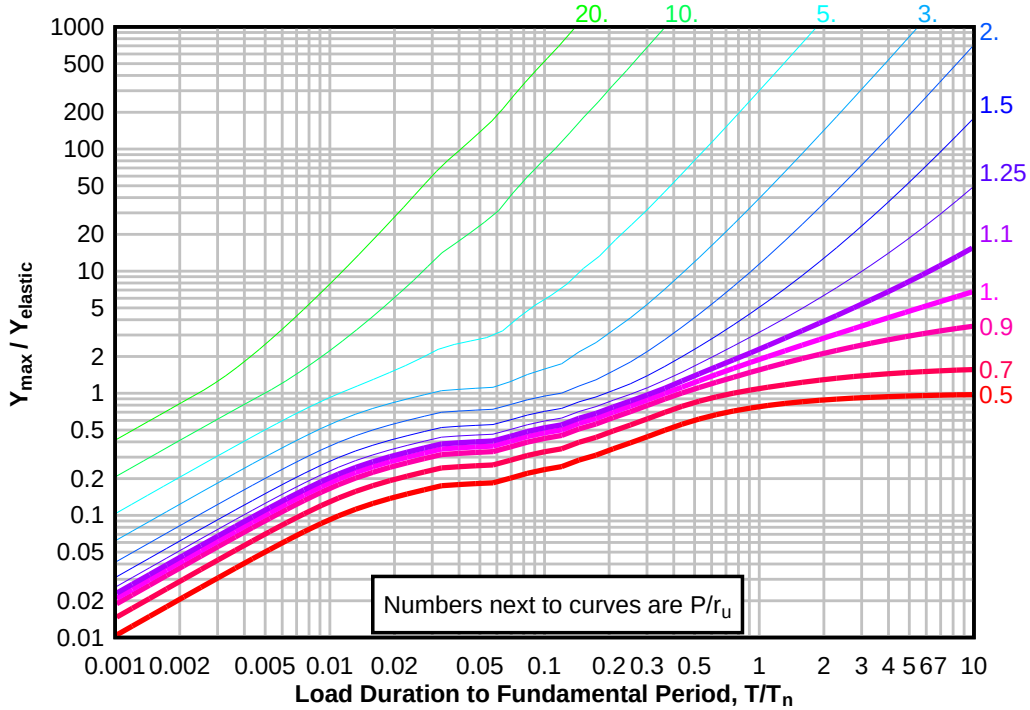


Figure 3-129(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.178, C2 = 30)

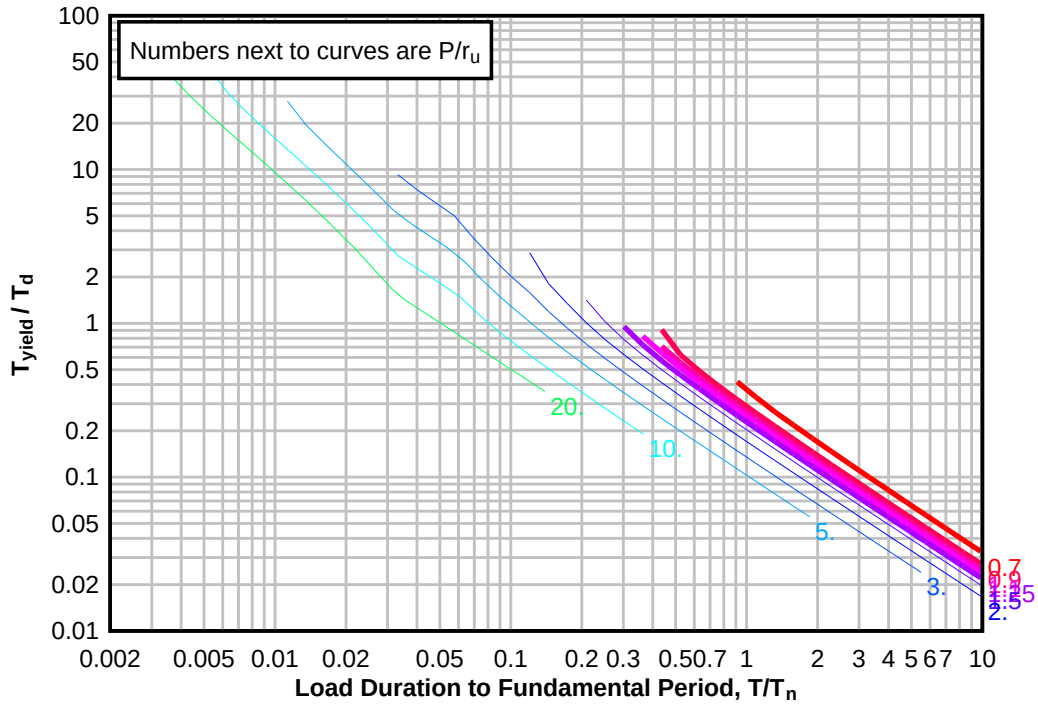


Figure 3-130 (a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.147, C_2 = 30)

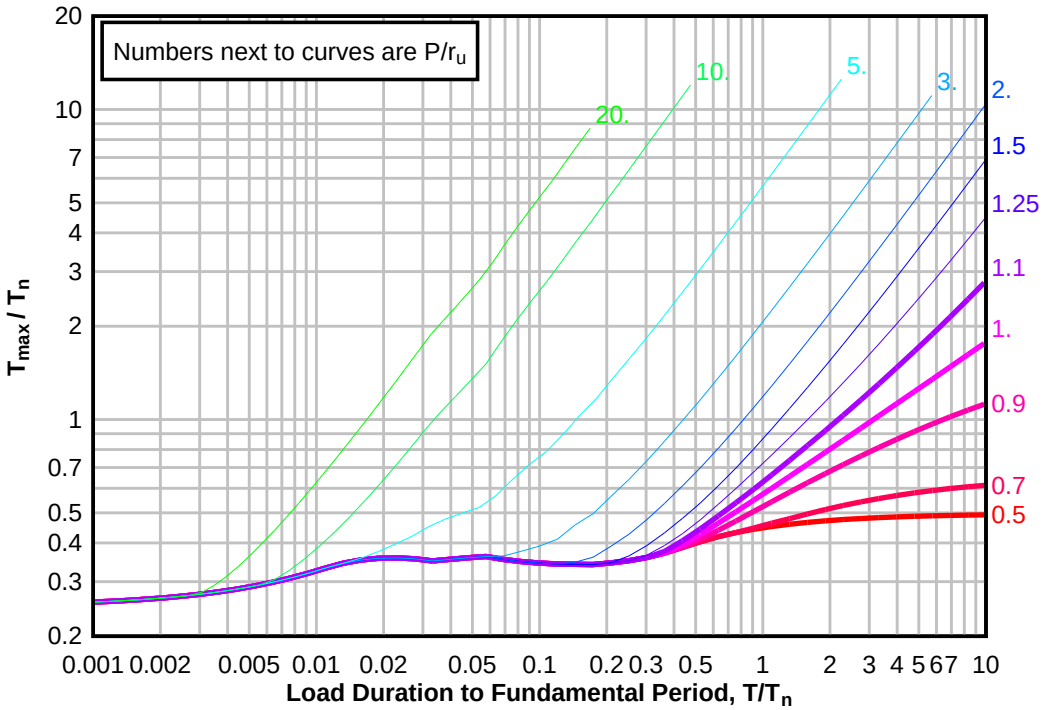


Figure 3-130 (b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.147, C2 = 30)

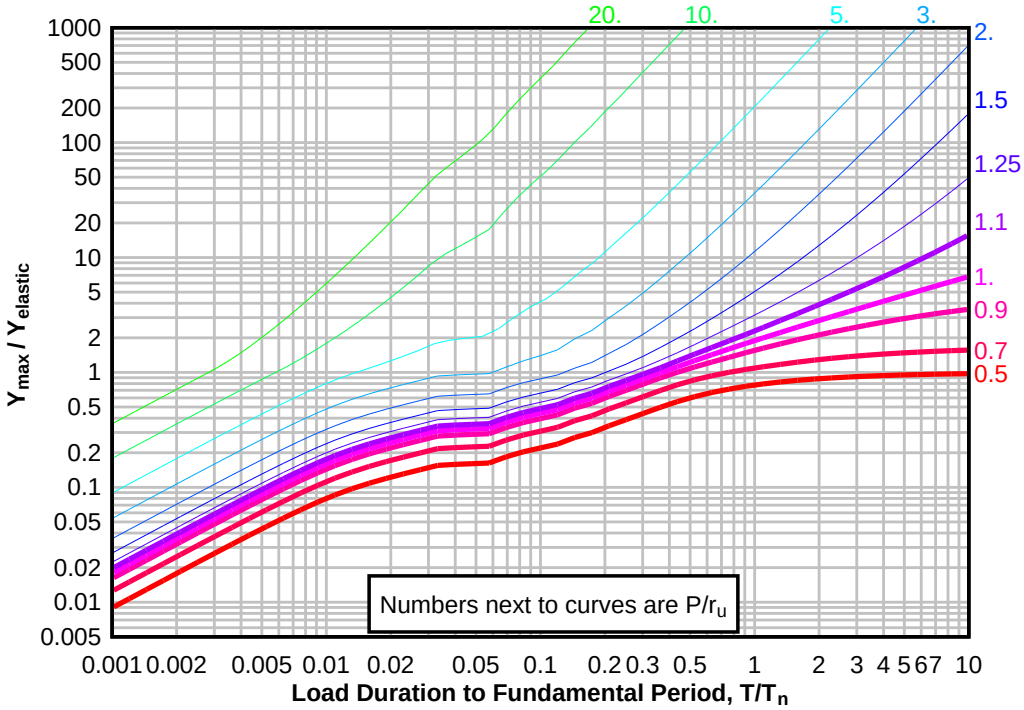


Figure 3-130(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.147, C2 = 30)

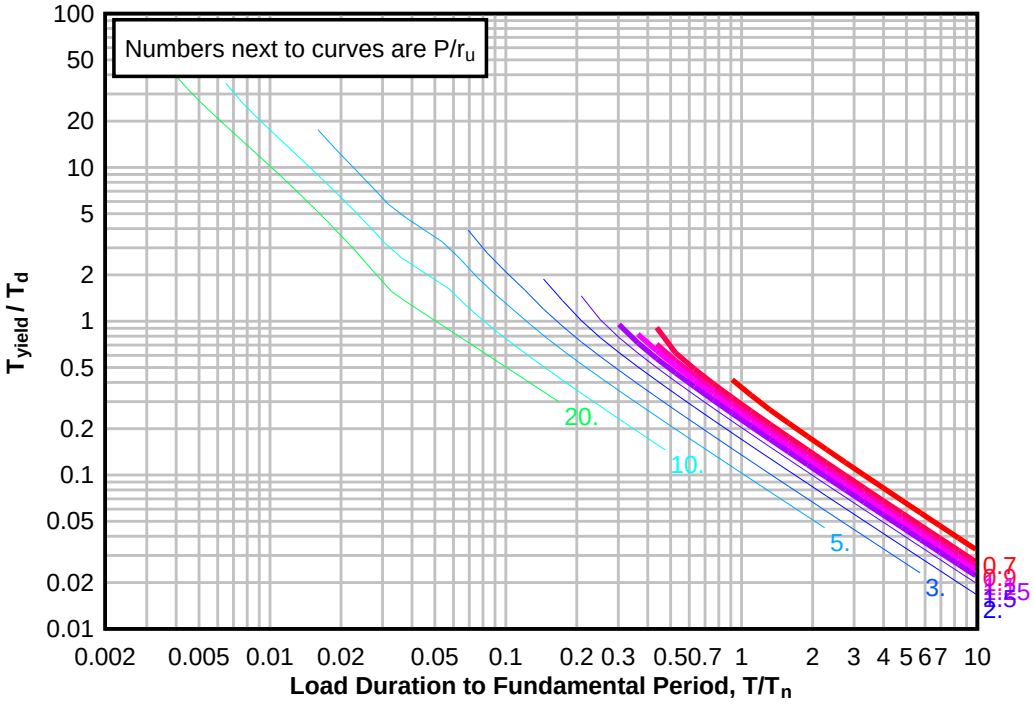


Figure 3-131(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.121, C_2 = 30)

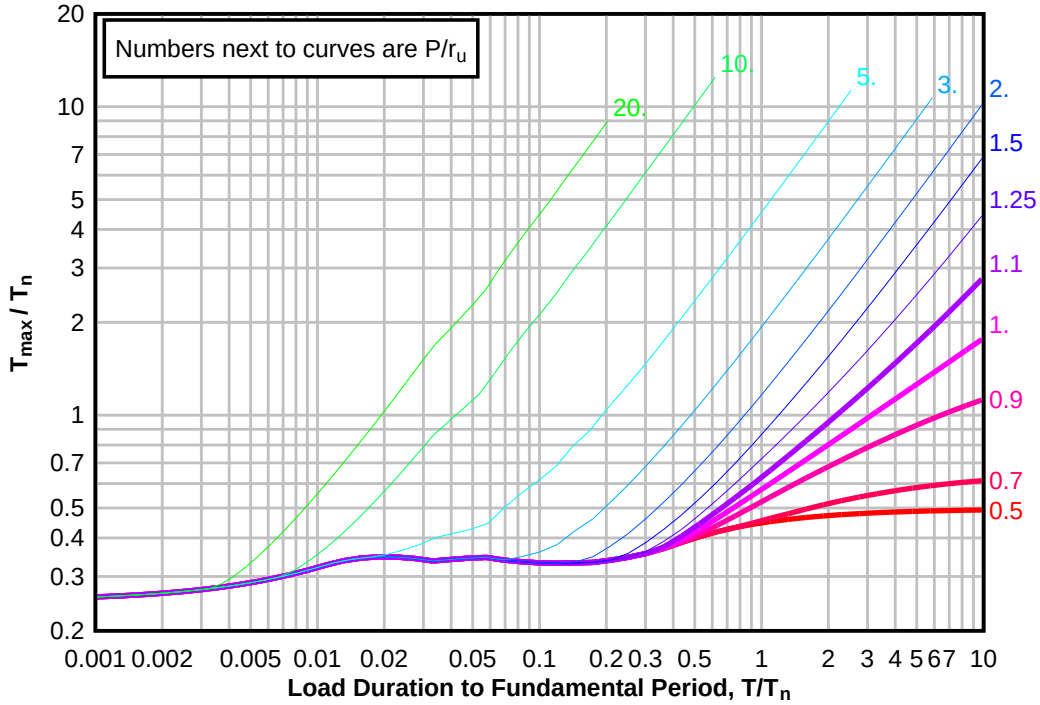


Figure 3-131 (b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.121, C2 = 30)

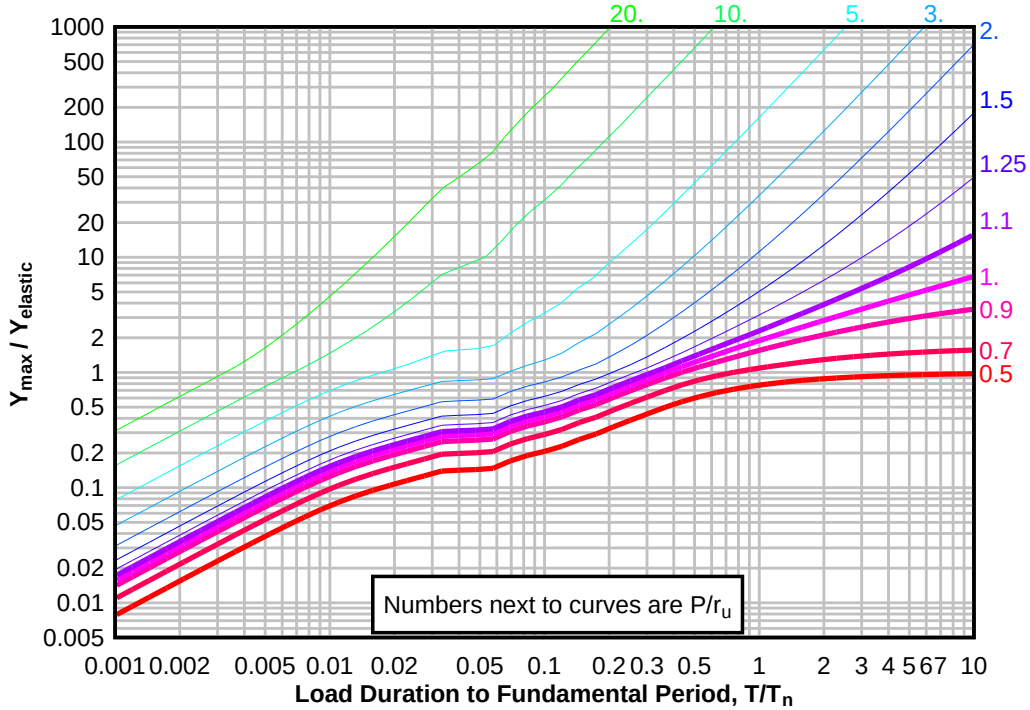


Figure 3-131 (c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.121, C2 = 30)

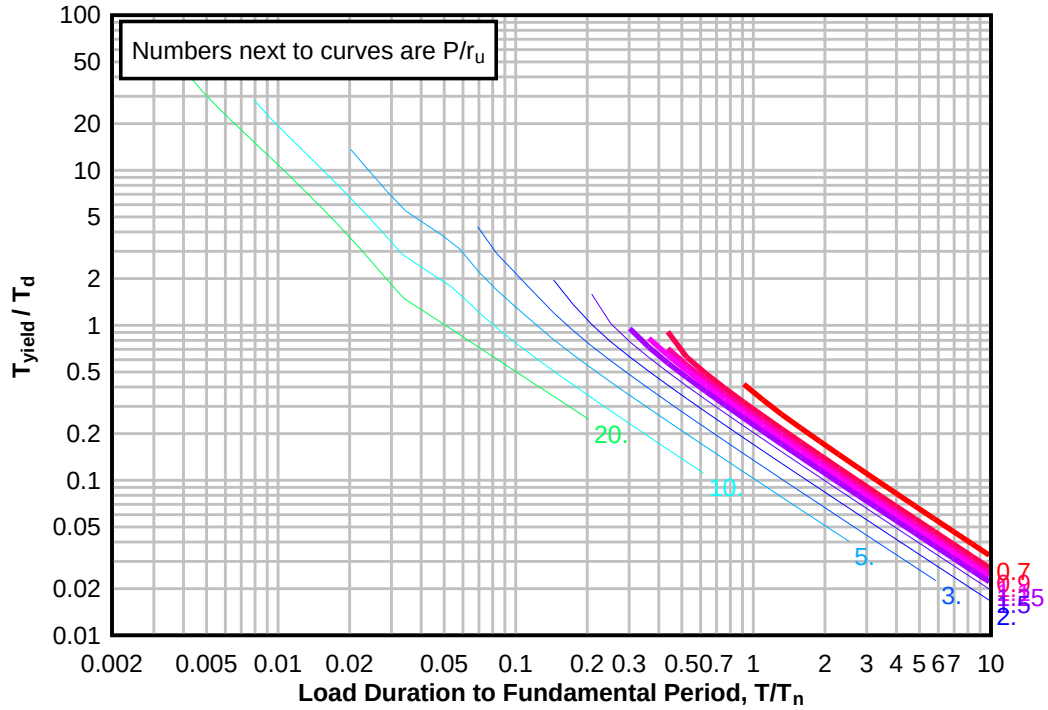


Figure 3-132 (a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.100, C_2 = 30)

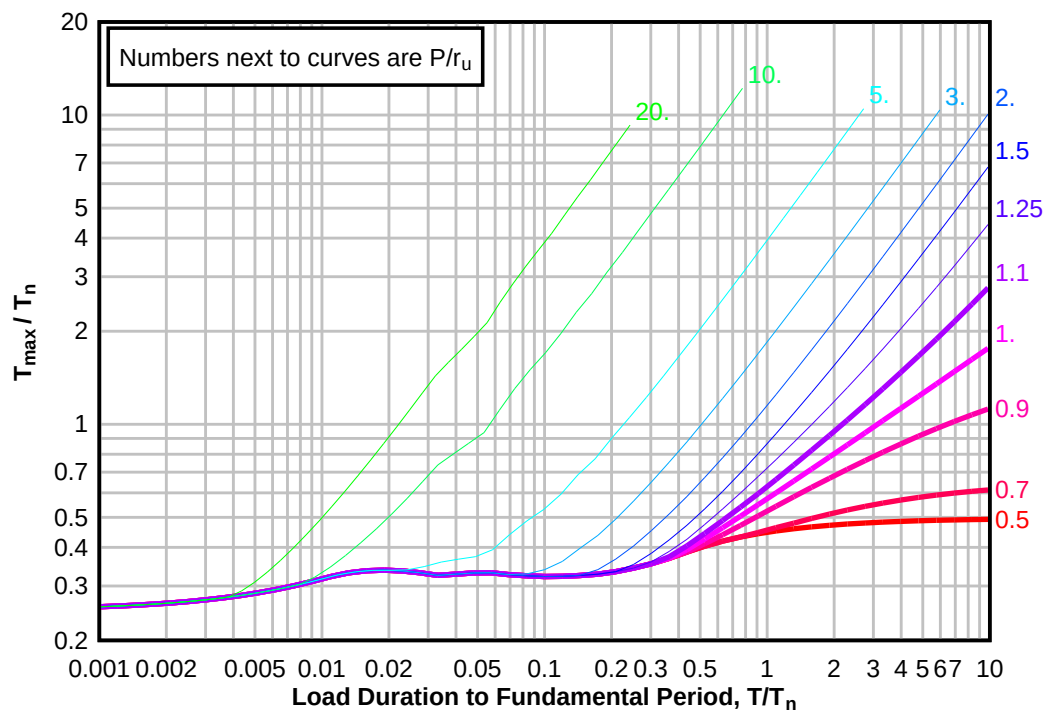


Figure 3-132(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.100, C2 = 30)

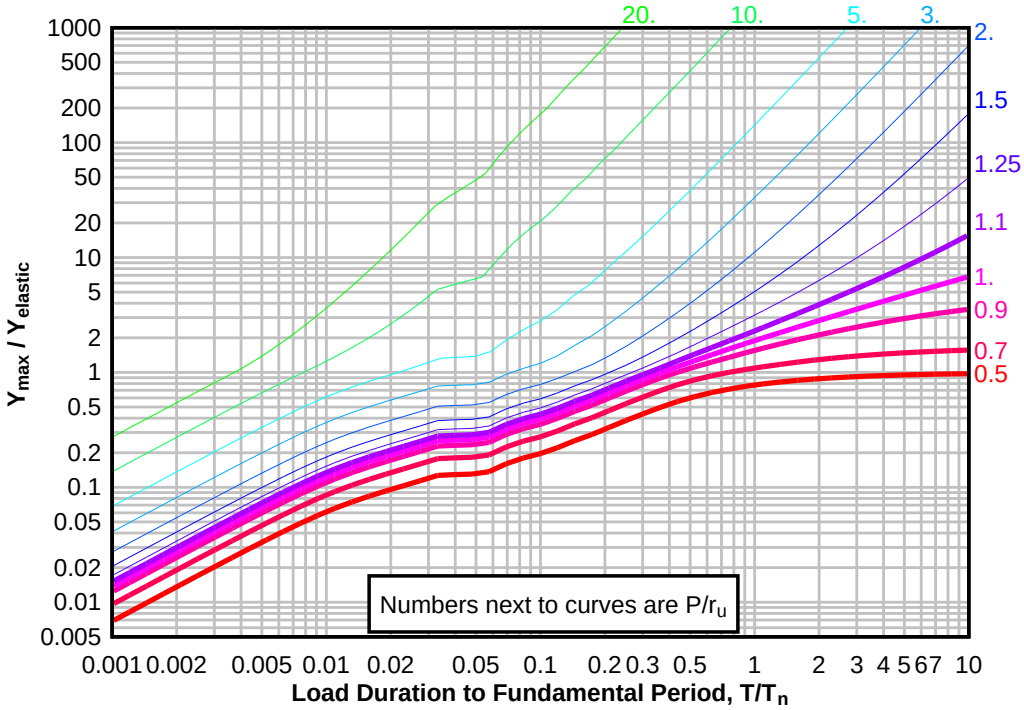


Figure 3-132(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.100, C2 = 30)

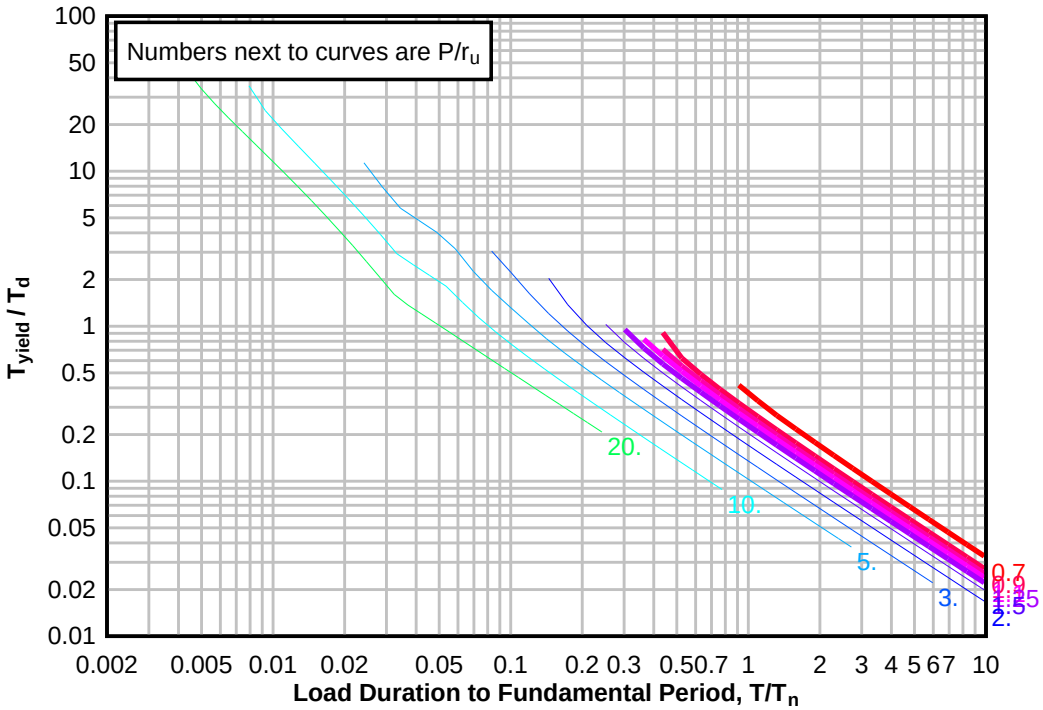


Figure 3-133(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.075, C_2 = 30)

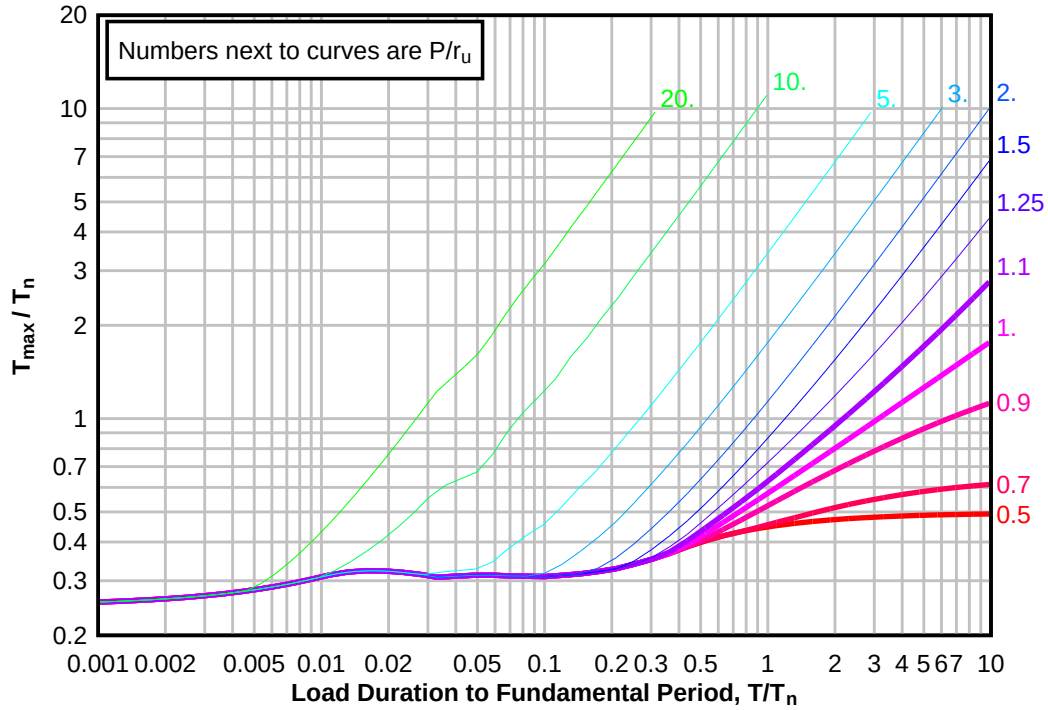


Figure 3-133(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.075, C2 = 30)

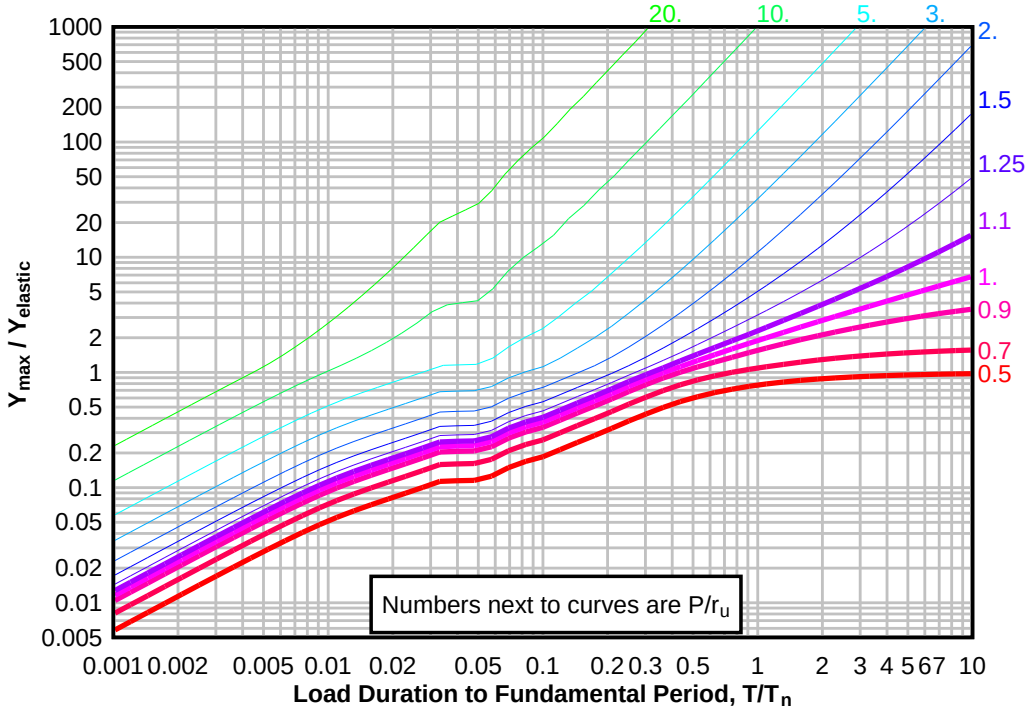


Figure 3-133(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.075, C2 = 30)

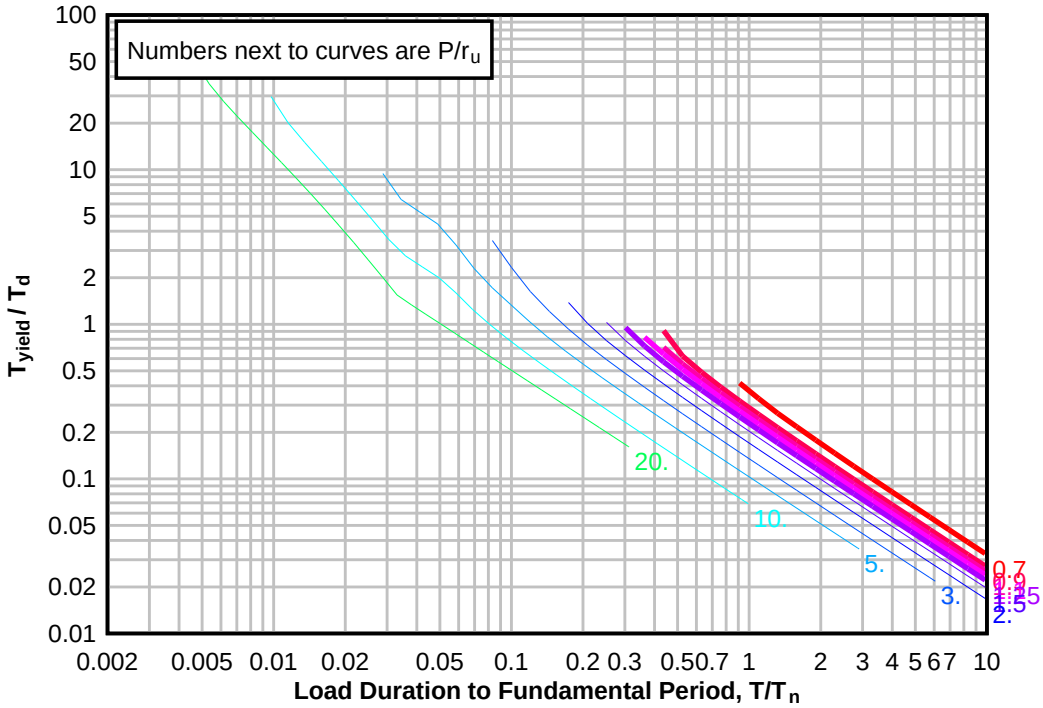


Figure 3-134 (a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.056, C_2 = 30)

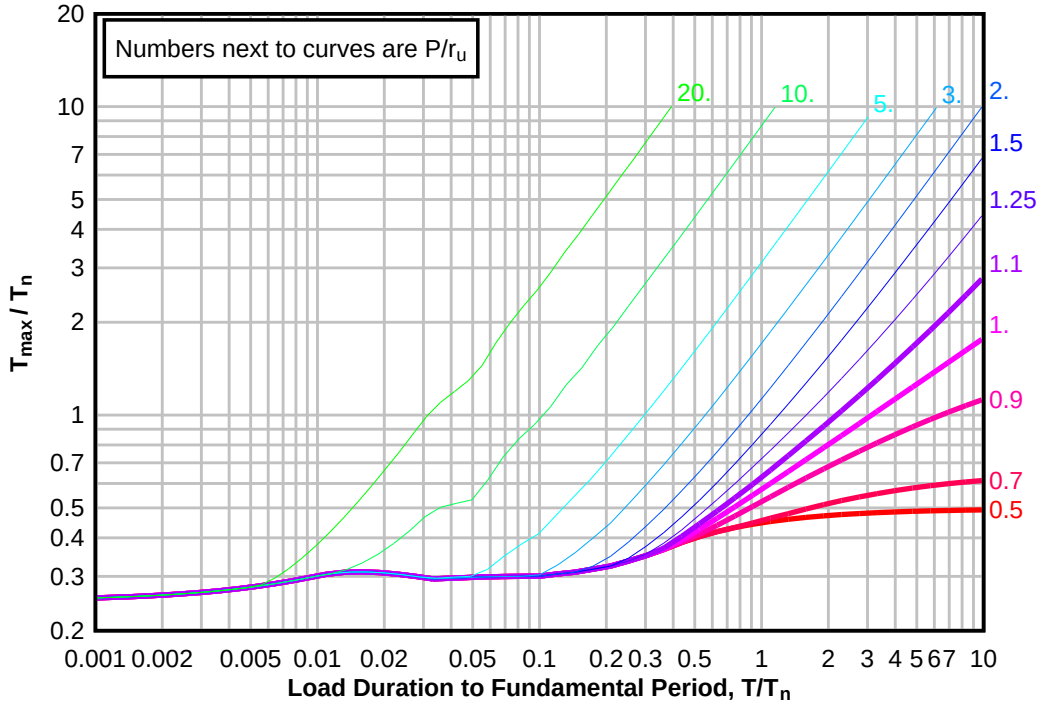


Figure 3-134(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.056, C2 = 30)

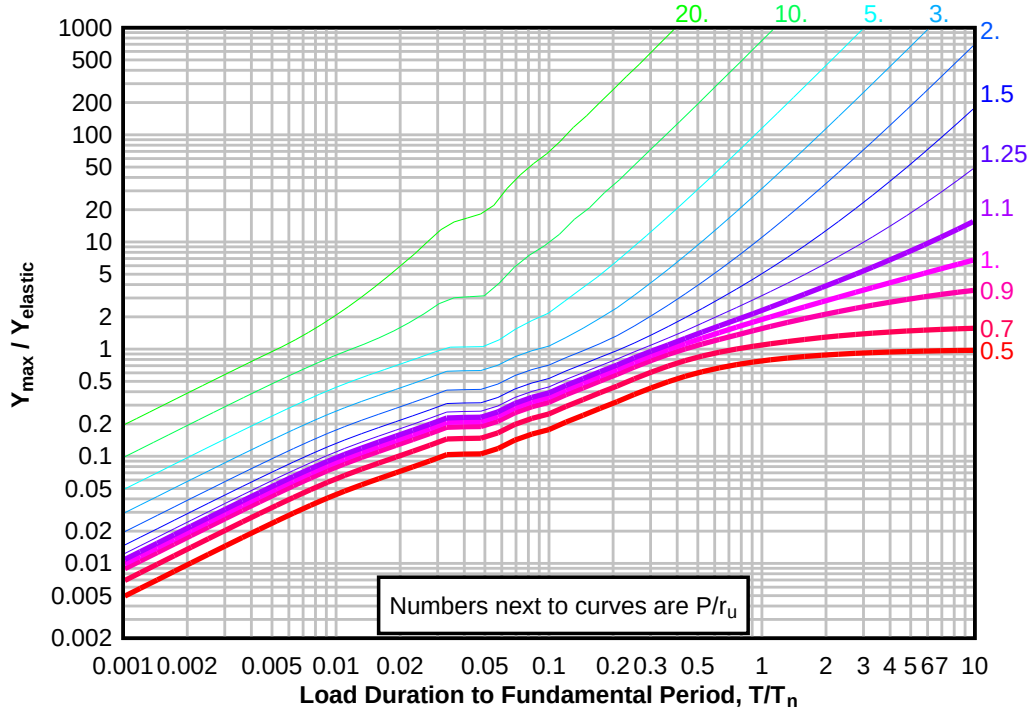


Figure 3-134(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.056, C2 = 30)

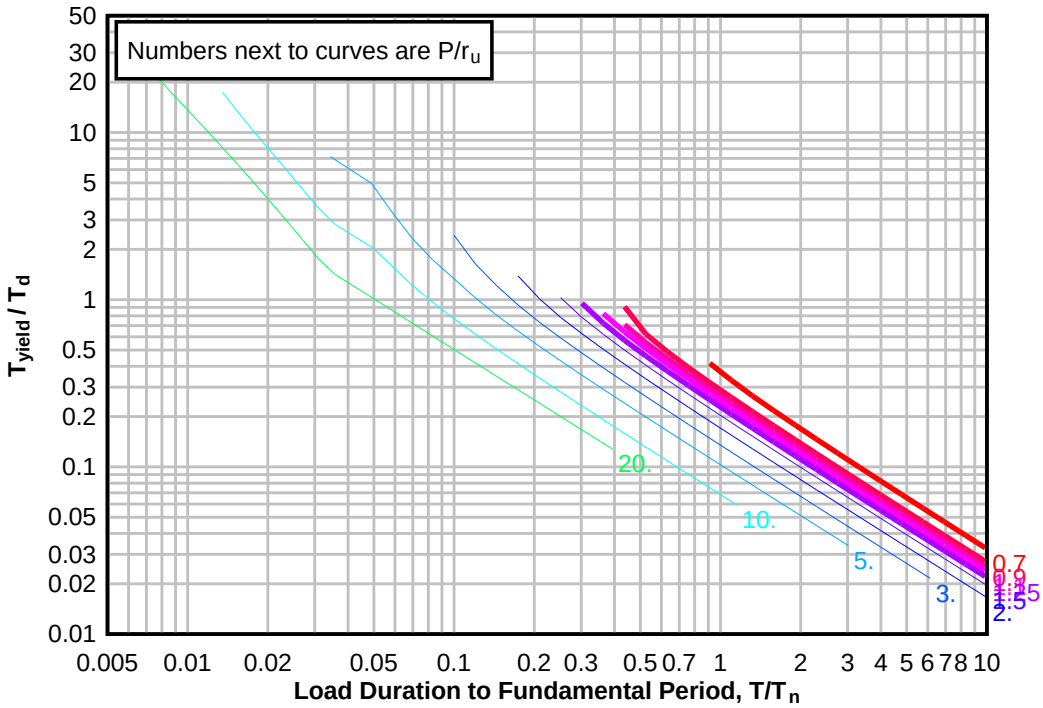


Figure 3-135(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.042, C_2 = 30)

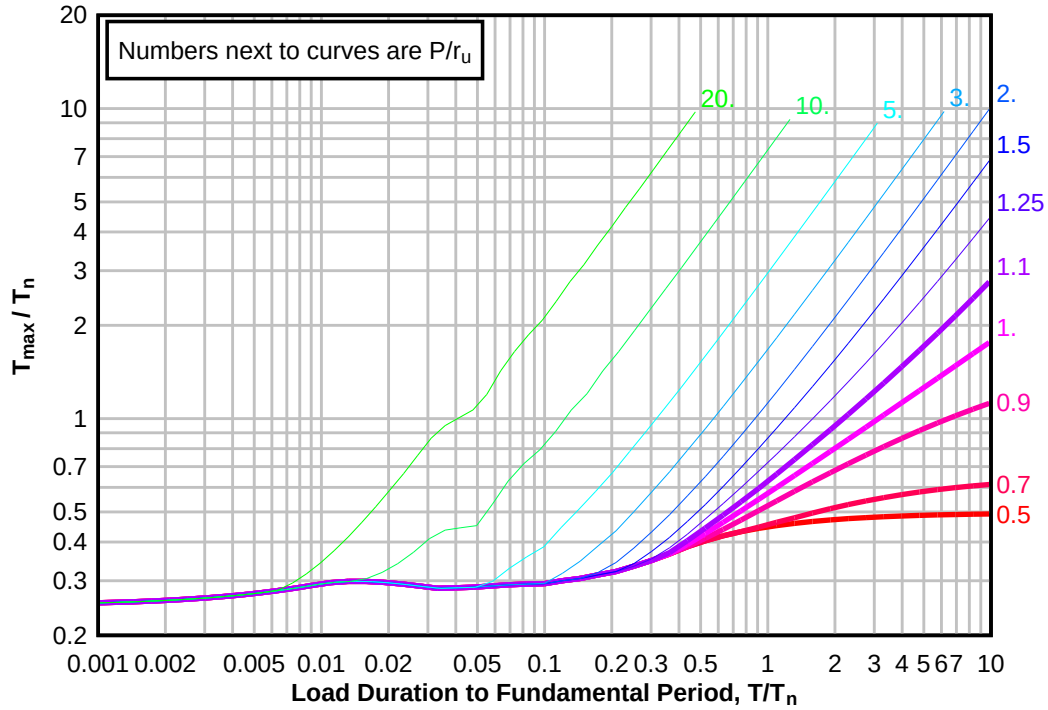


Figure 3-135(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.042, C2 = 30)

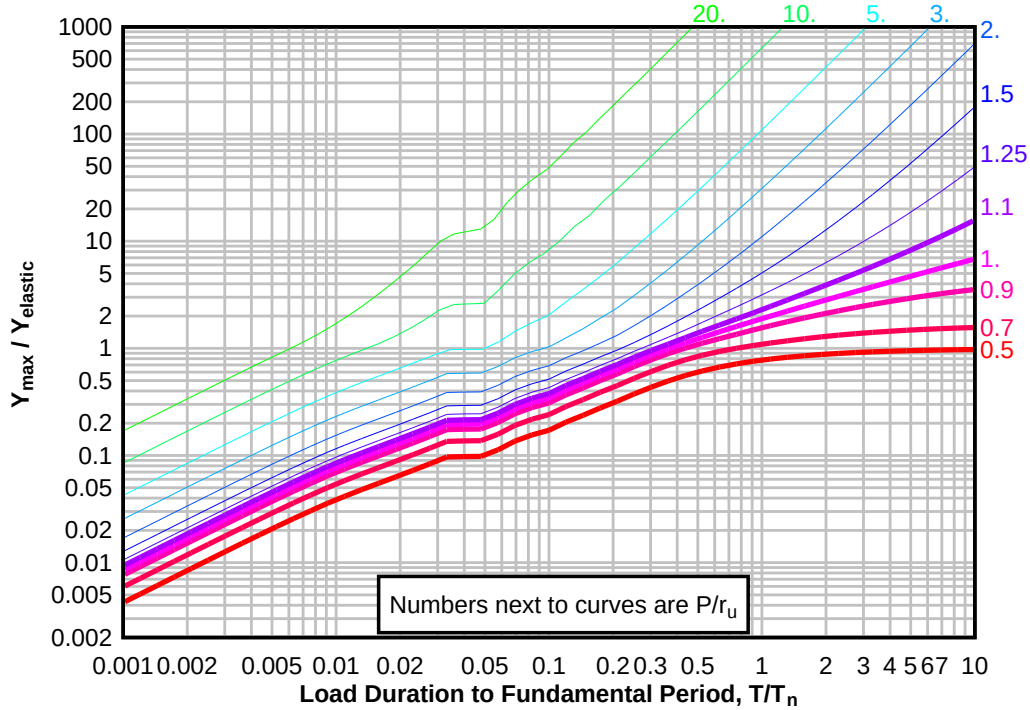


Figure 3-135(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.042, C2 = 30)

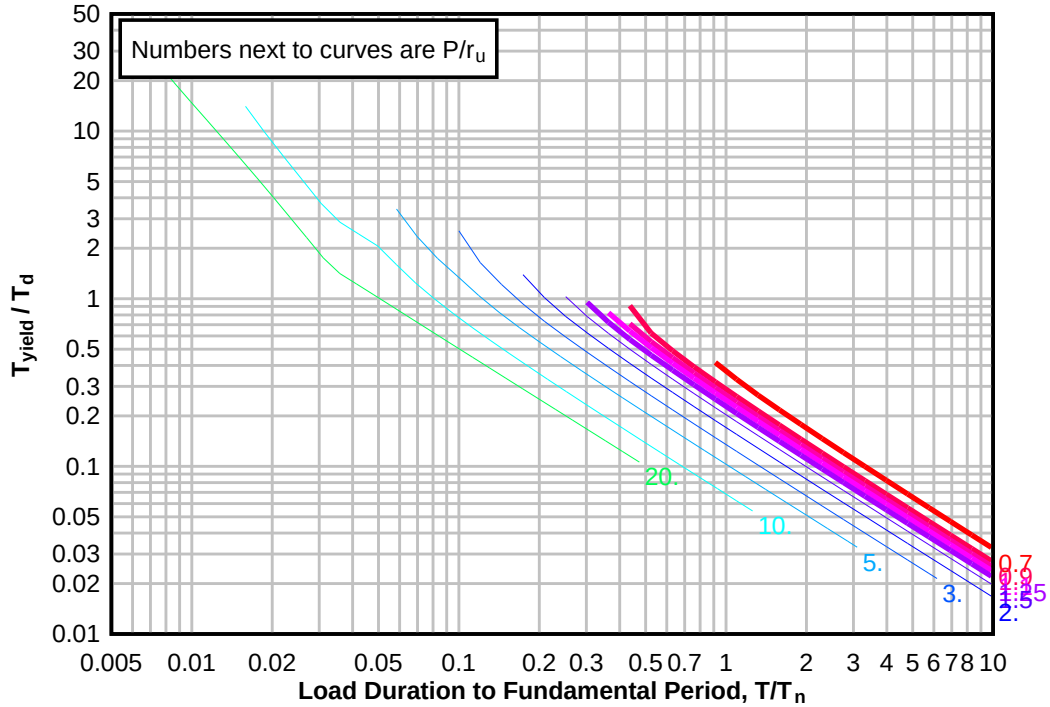


Figure 3-136(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.032, C_2 = 30)

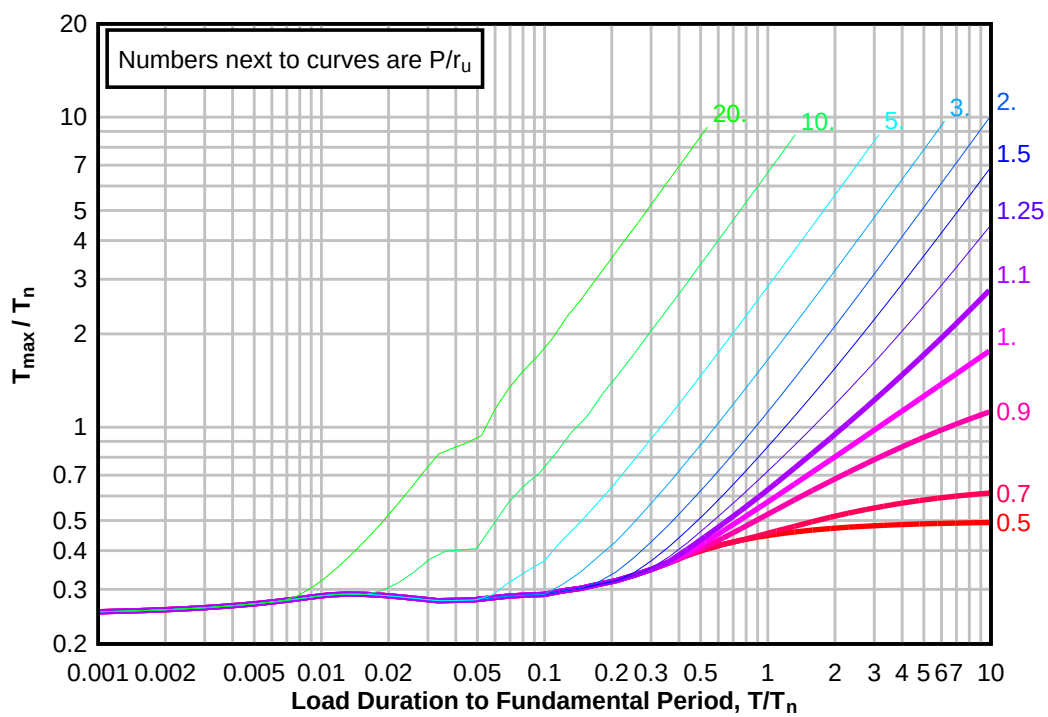


Figure 3-136(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.032, C2 = 30)

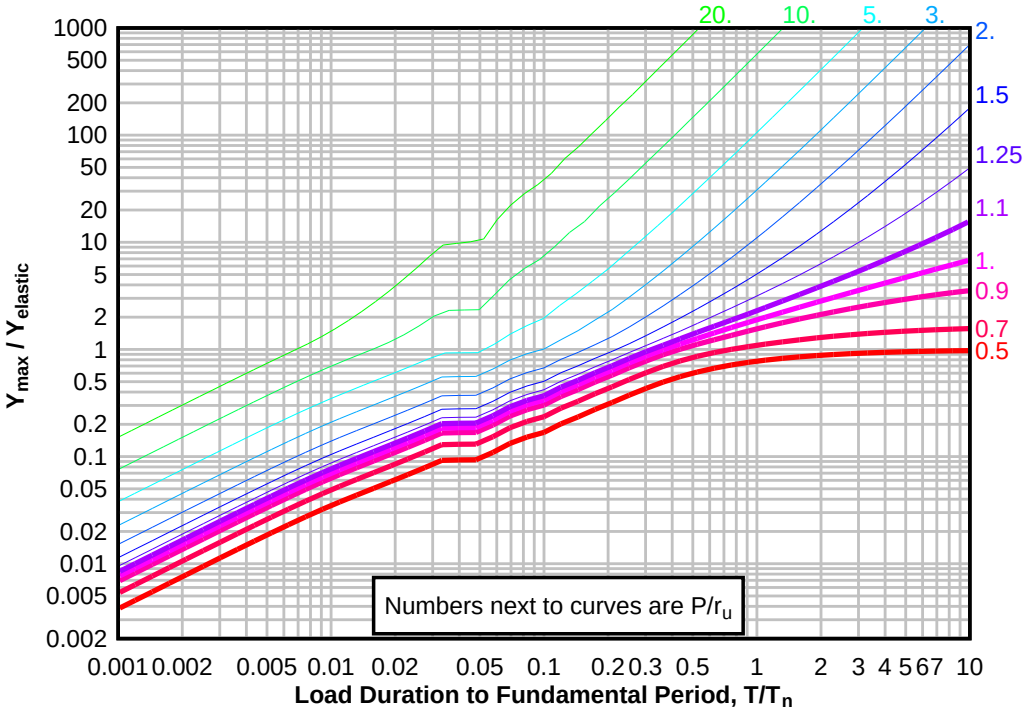


Figure 3-136(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.032, C2 = 30)

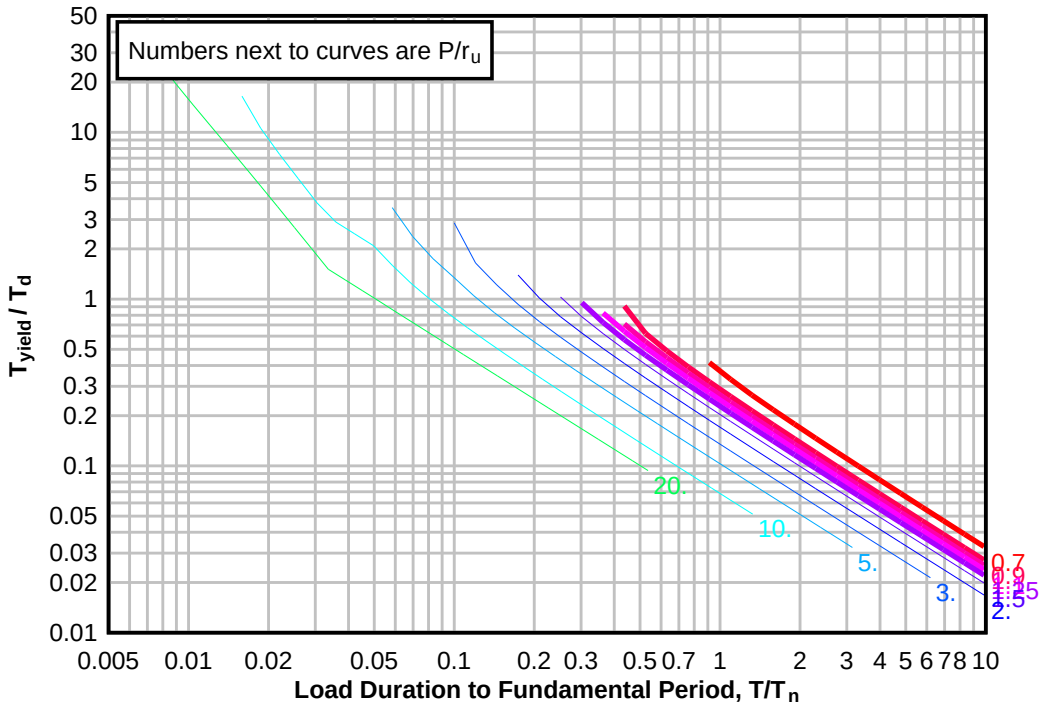


Figure 3-137(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.026, C_2 = 30)

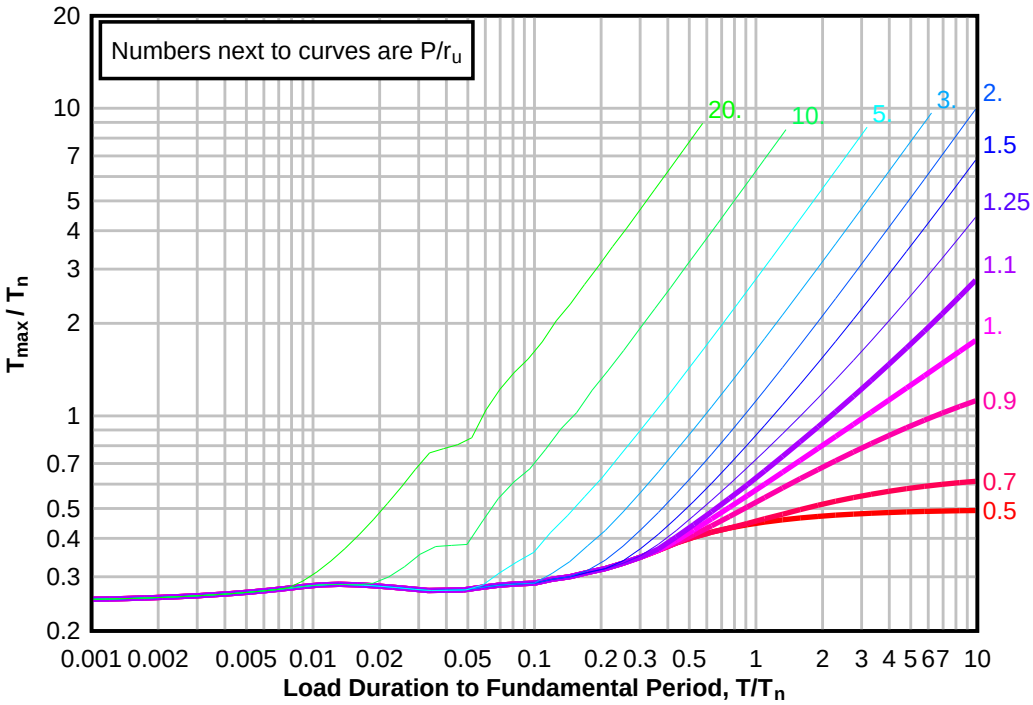


Figure 3-137(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.026, C2 = 30)

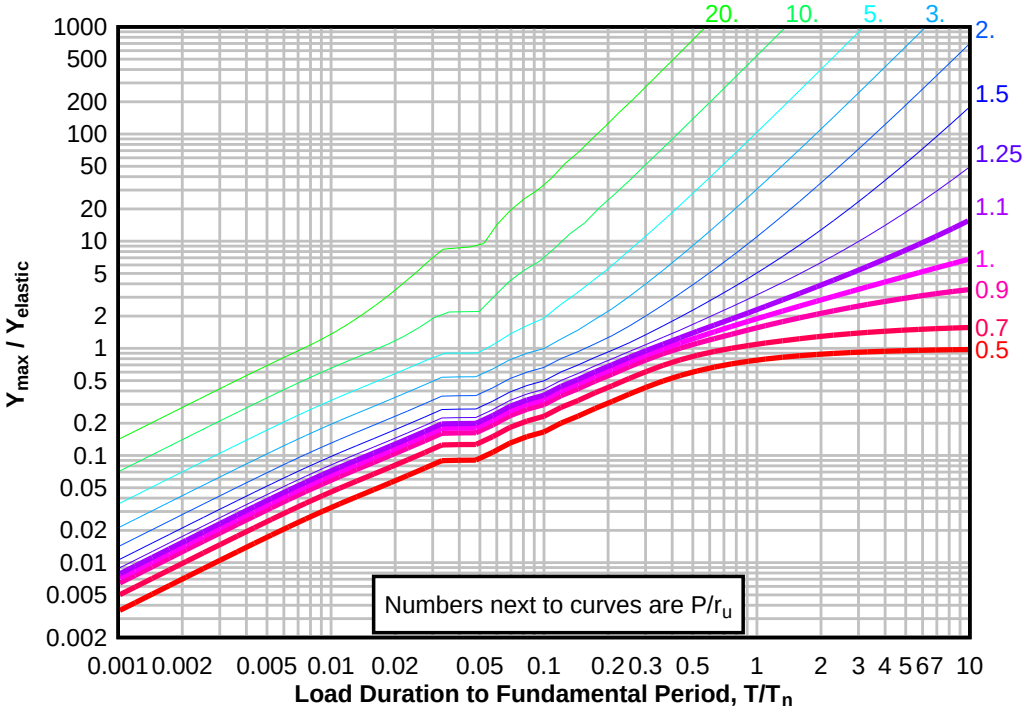


Figure 3-137(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.026, C2 = 30)

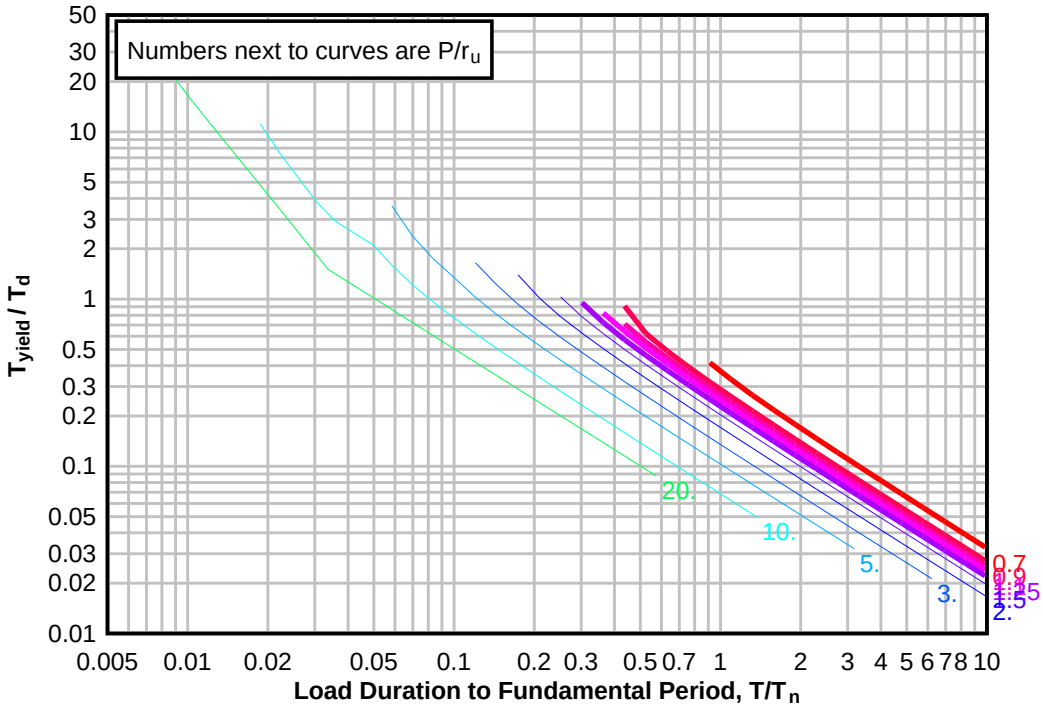


Figure 3-138(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.018, C_2 = 30)

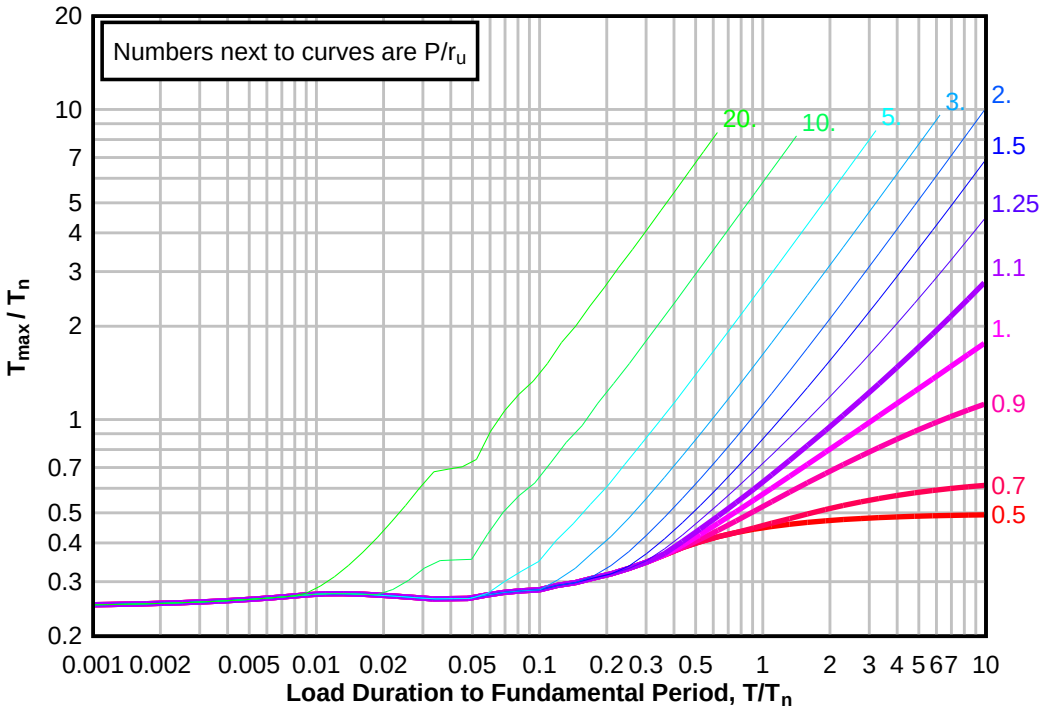


Figure 3-138(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.018, C2 = 30)

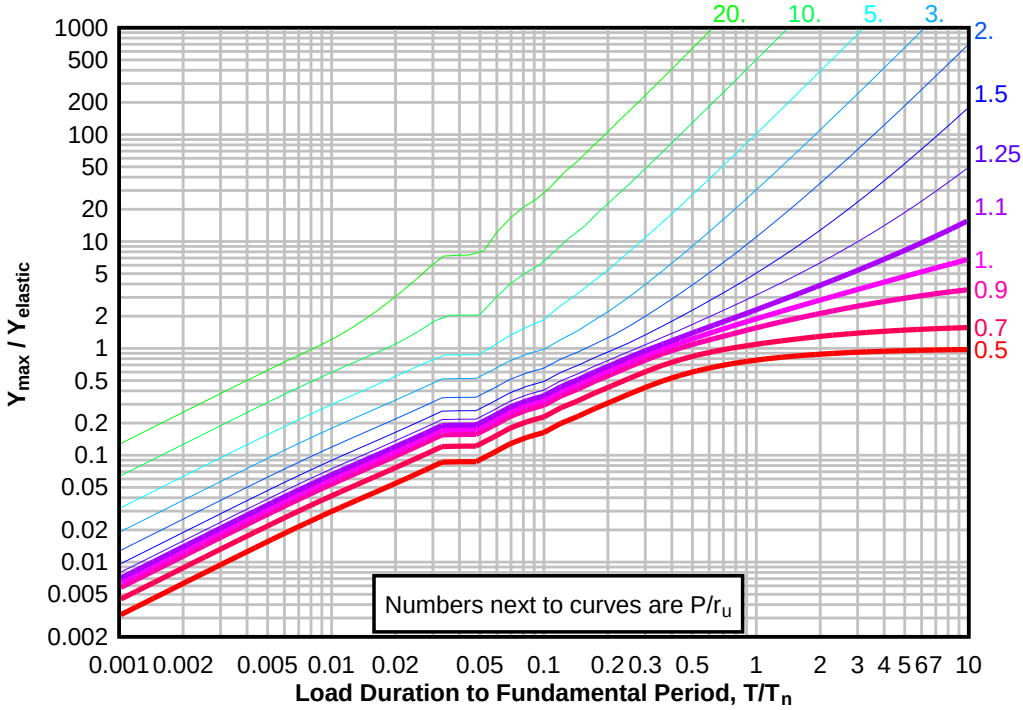


Figure 3-138(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.018, C2 = 30)

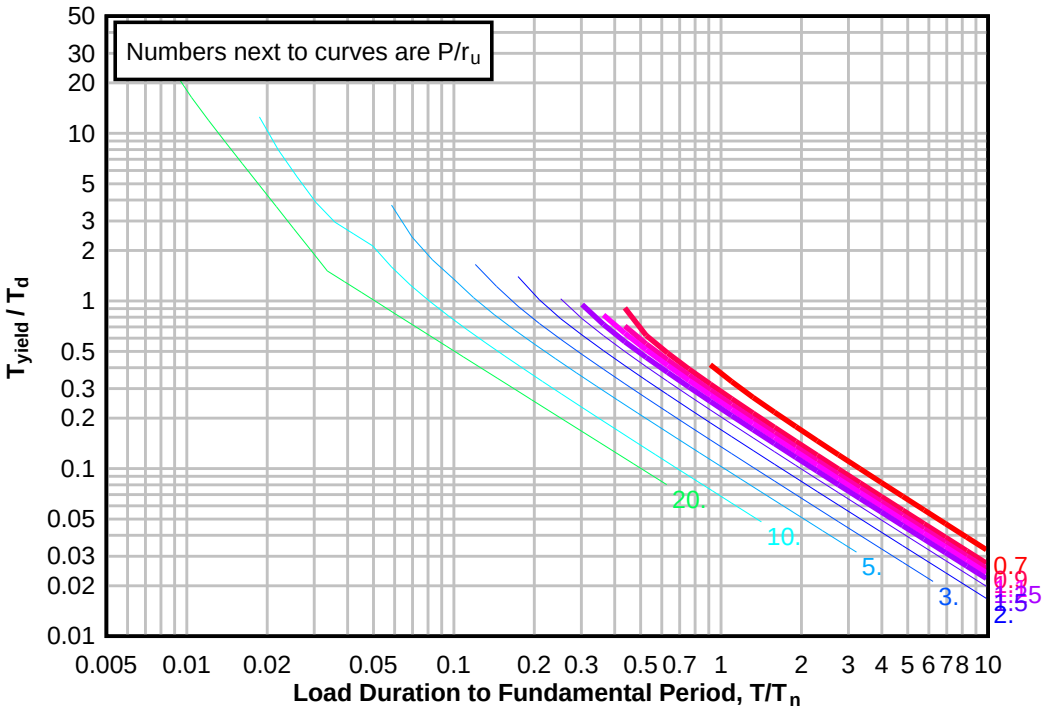


Figure 3-139(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.013, C_2 = 30)

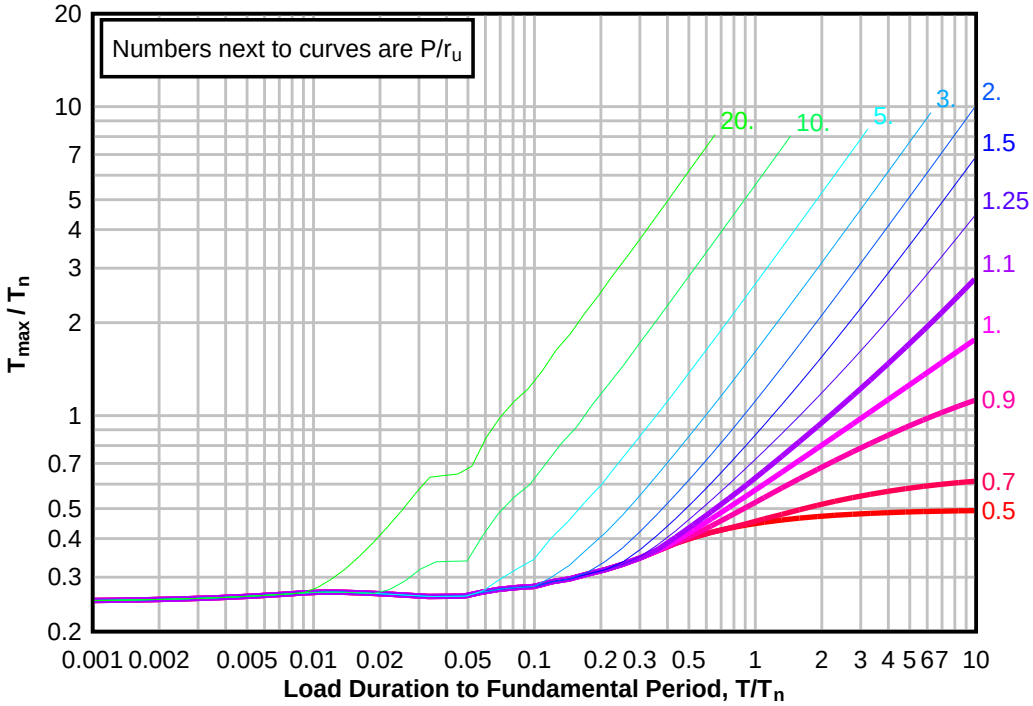


Figure 3-139(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.013, C2 = 30)

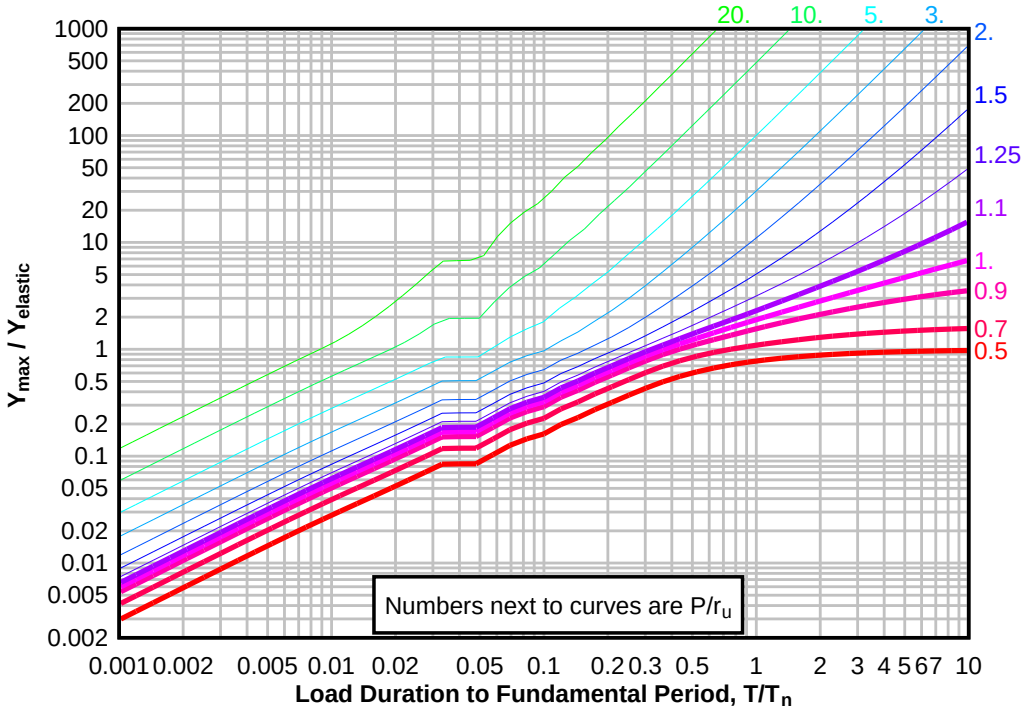


Figure 3-139(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.013, C2 = 30)

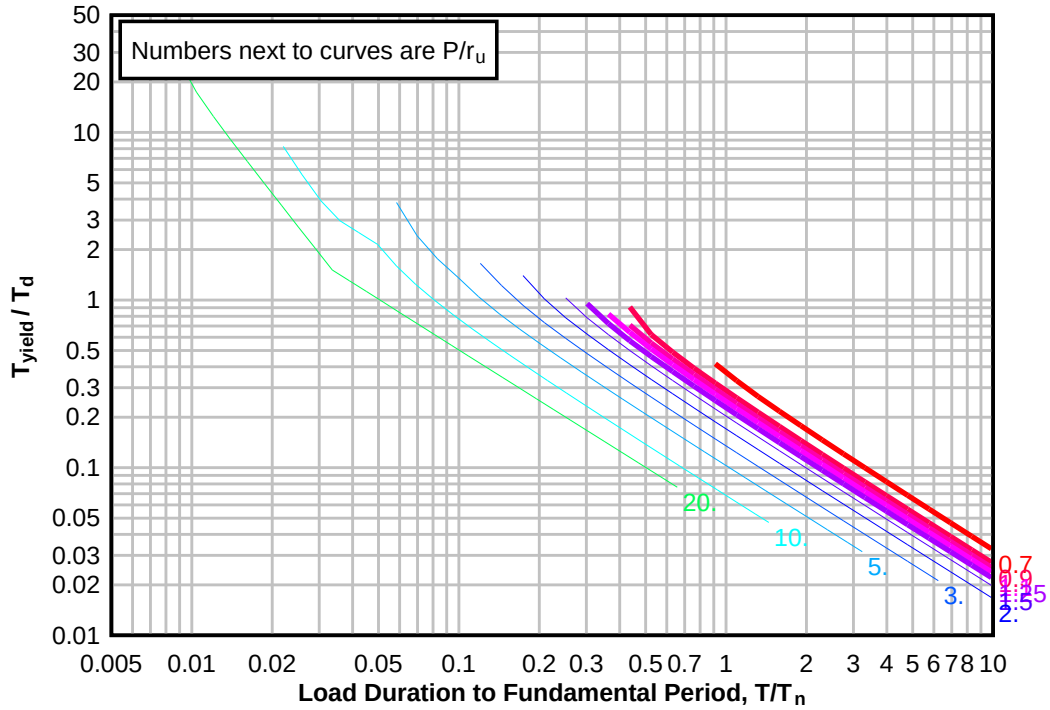


Figure 3-140(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.010, C_2 = 30)

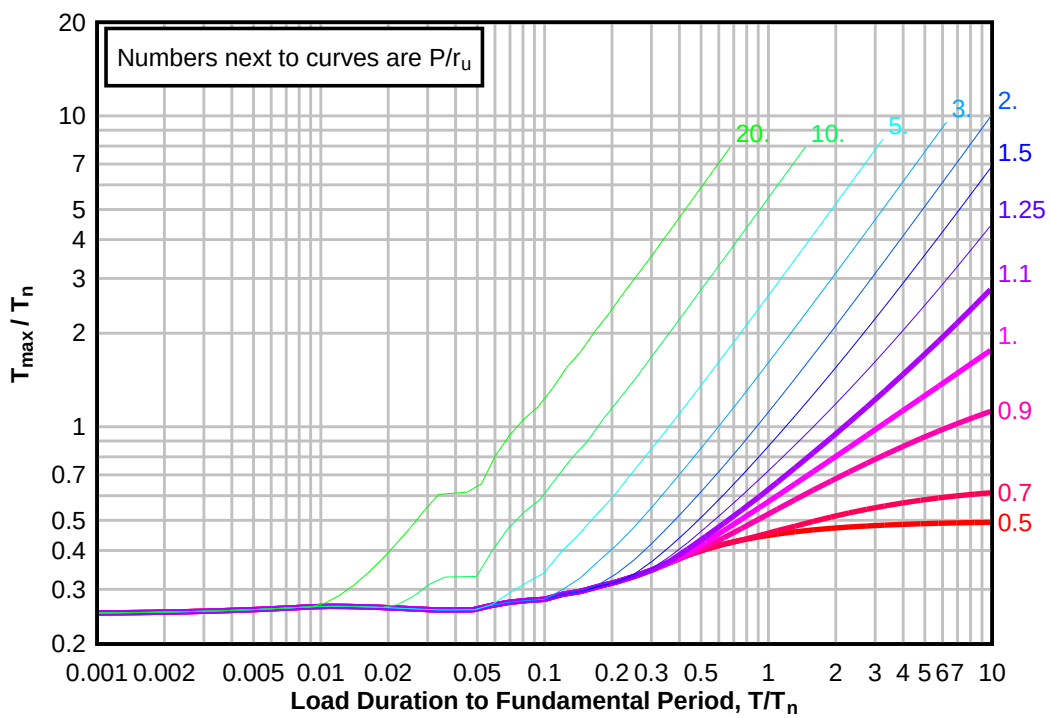


Figure 3-140(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.010, C2 = 30)

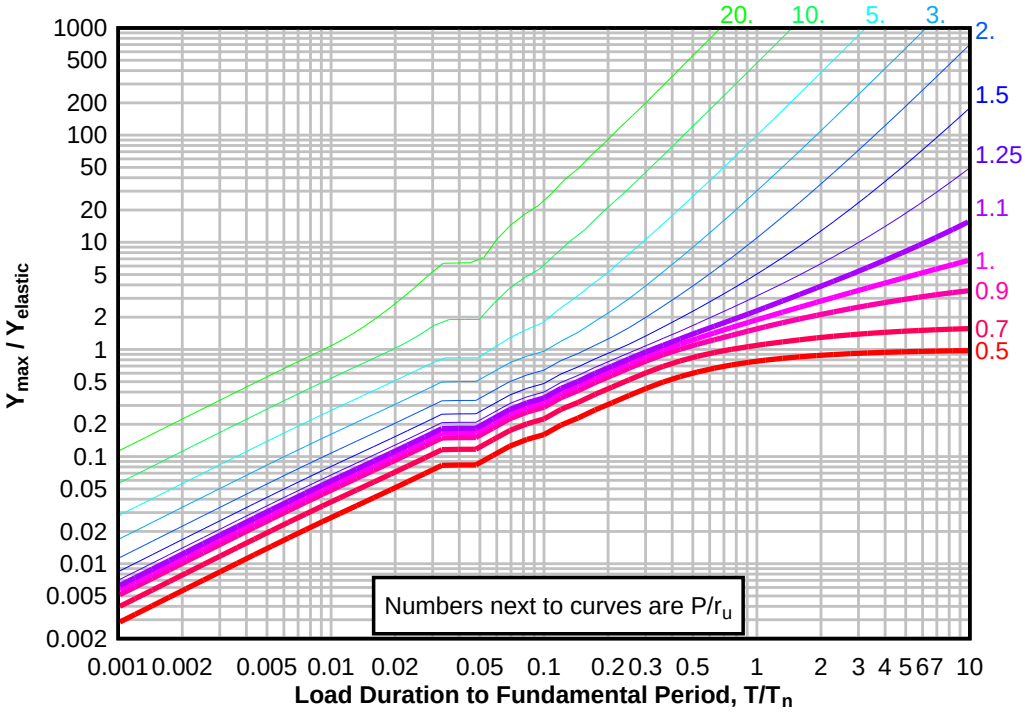


Figure 3-140(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.010, C2 = 30)

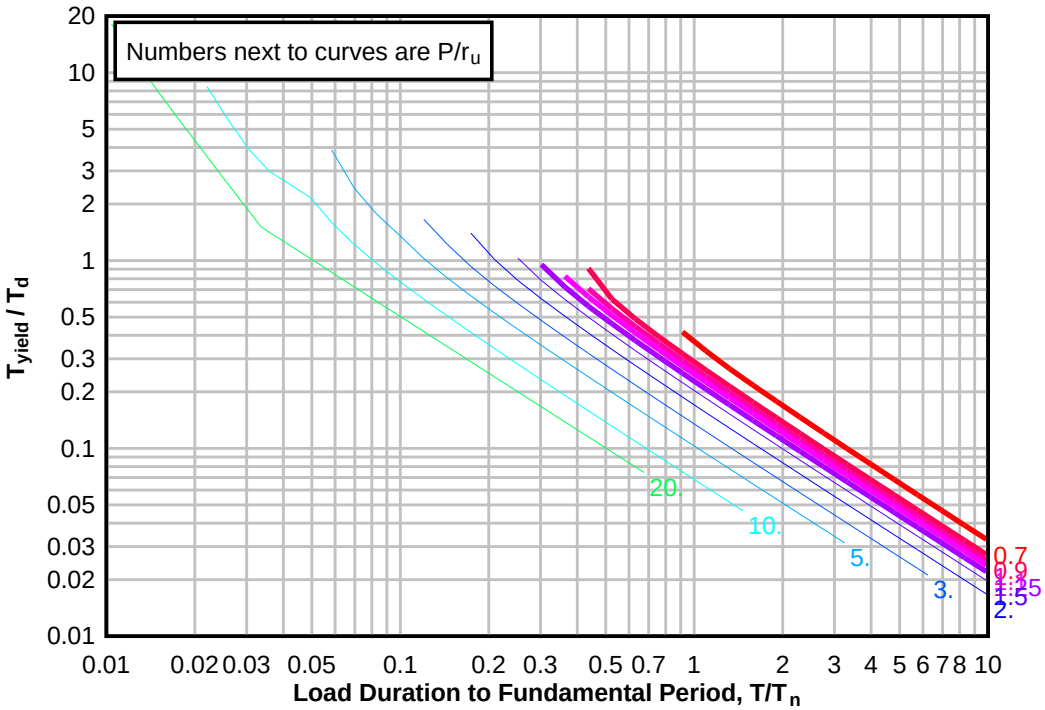


Figure 3-141(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.909, C_2 = 100)

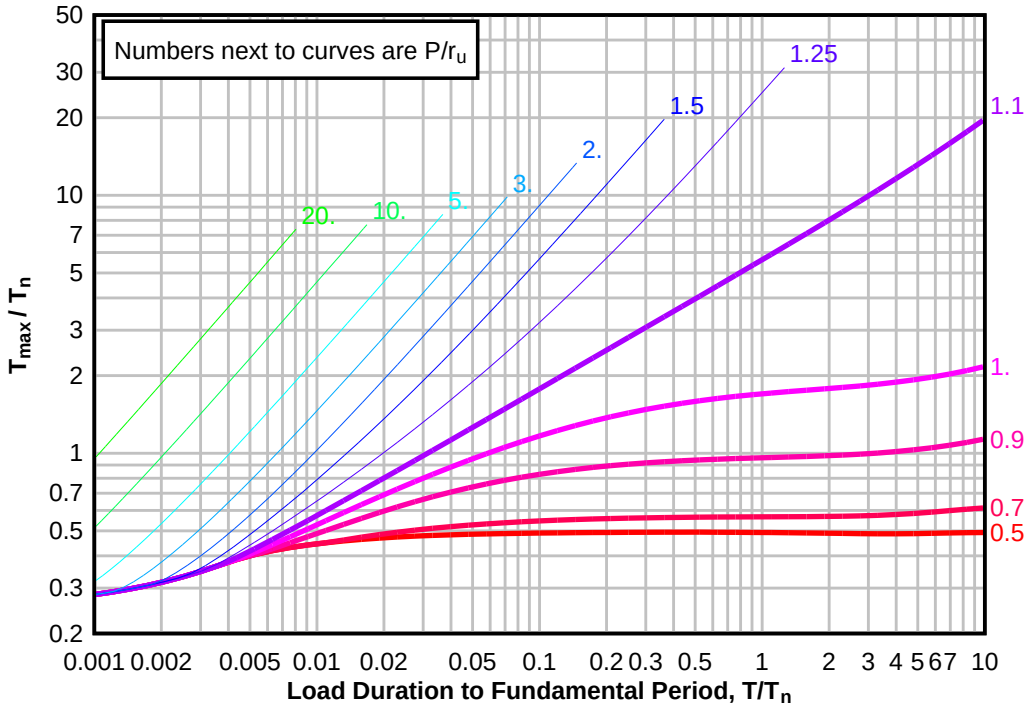


Figure 3-141(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.909, C2 = 100)

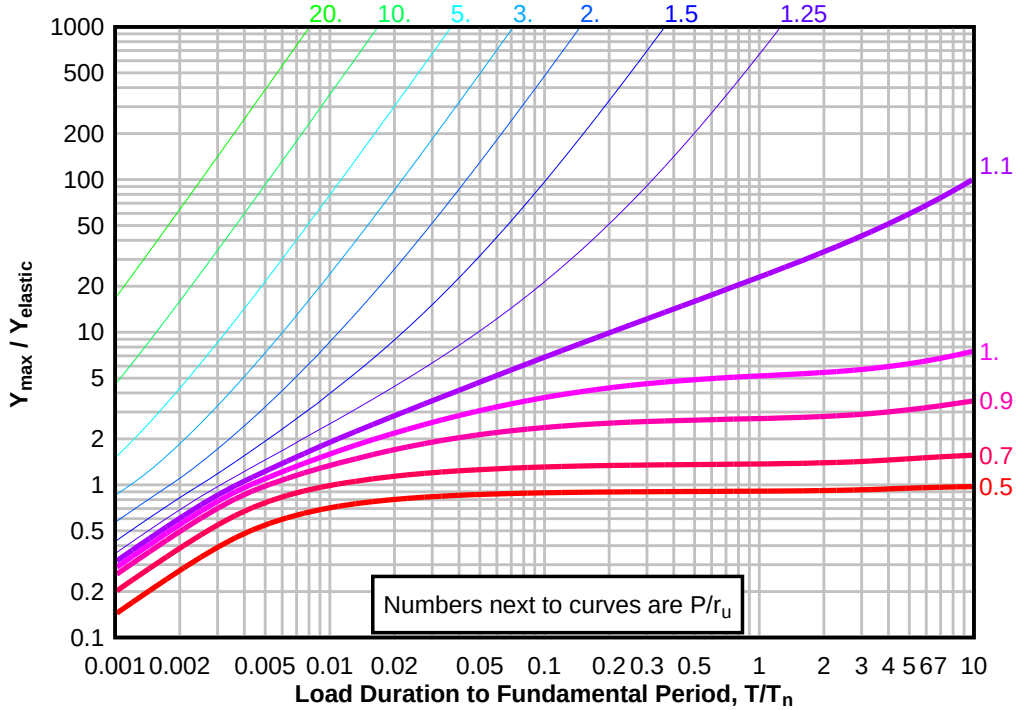


Figure 3-141(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.909, C2 = 100)

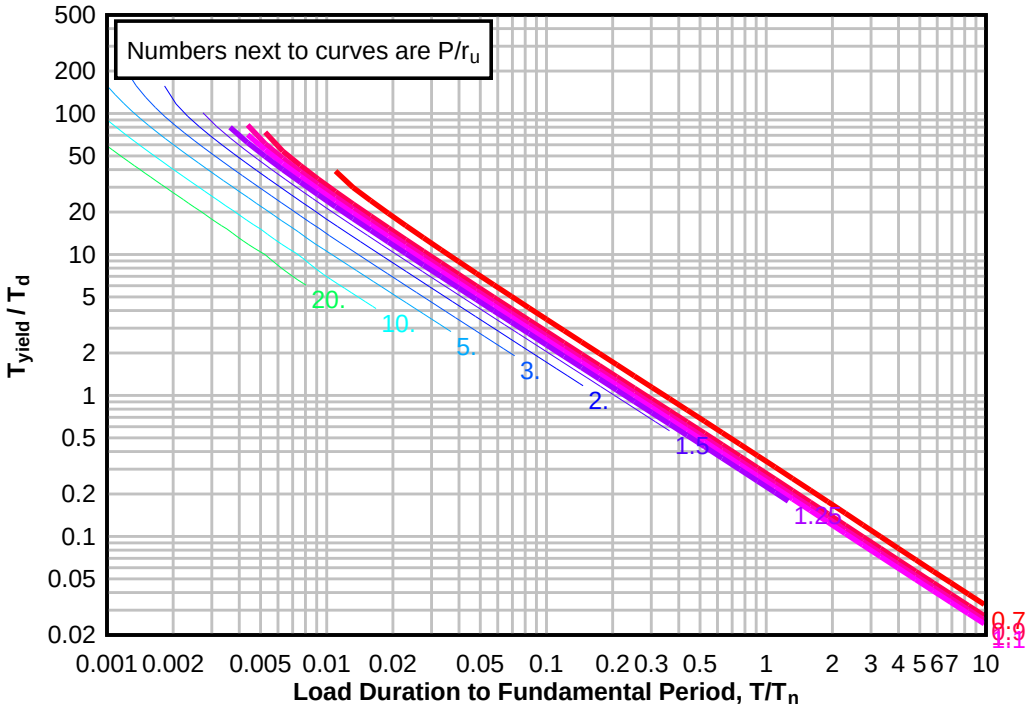


Figure 3-142 (a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.866, C_2 = 100)

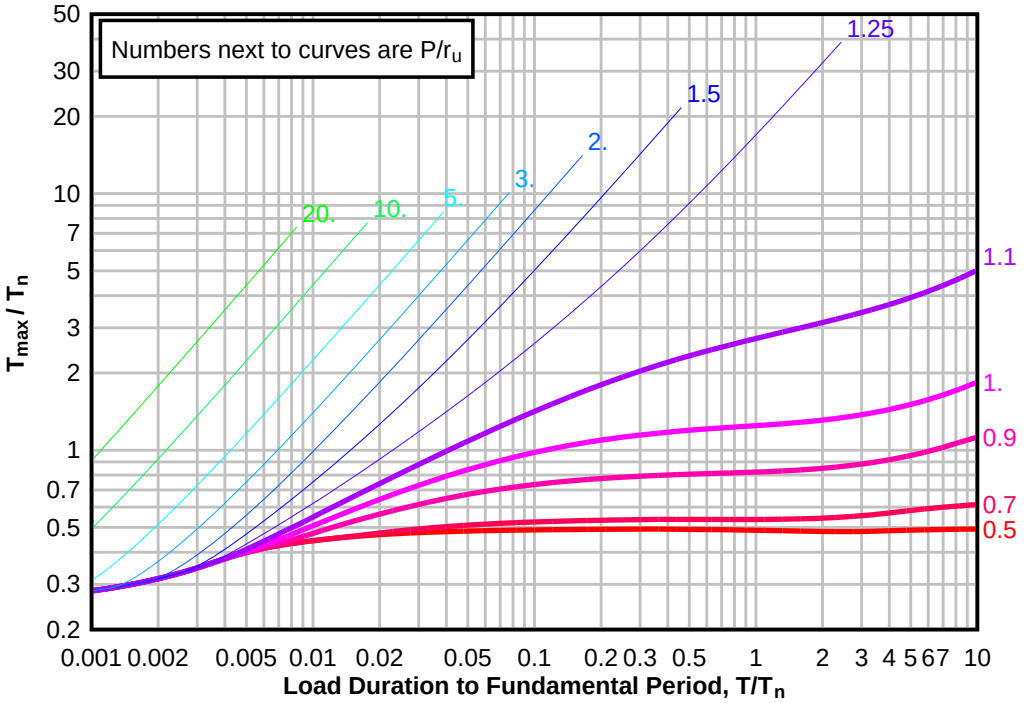


Figure 3142(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.866, C2 = 100)

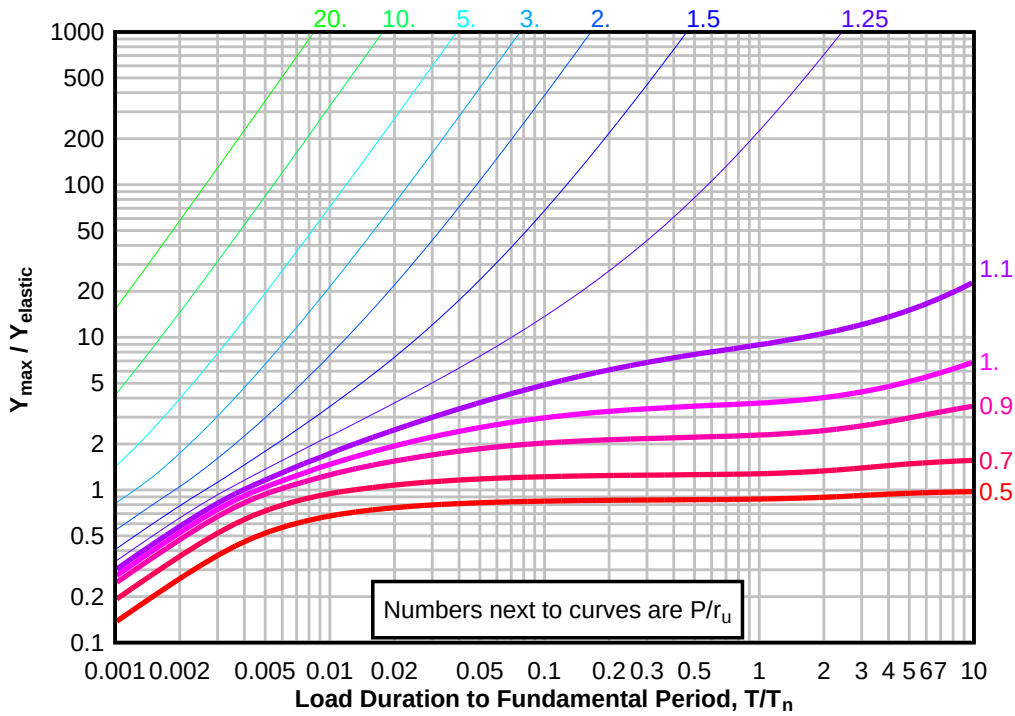


Figure 3-142(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.866, C2 = 100)

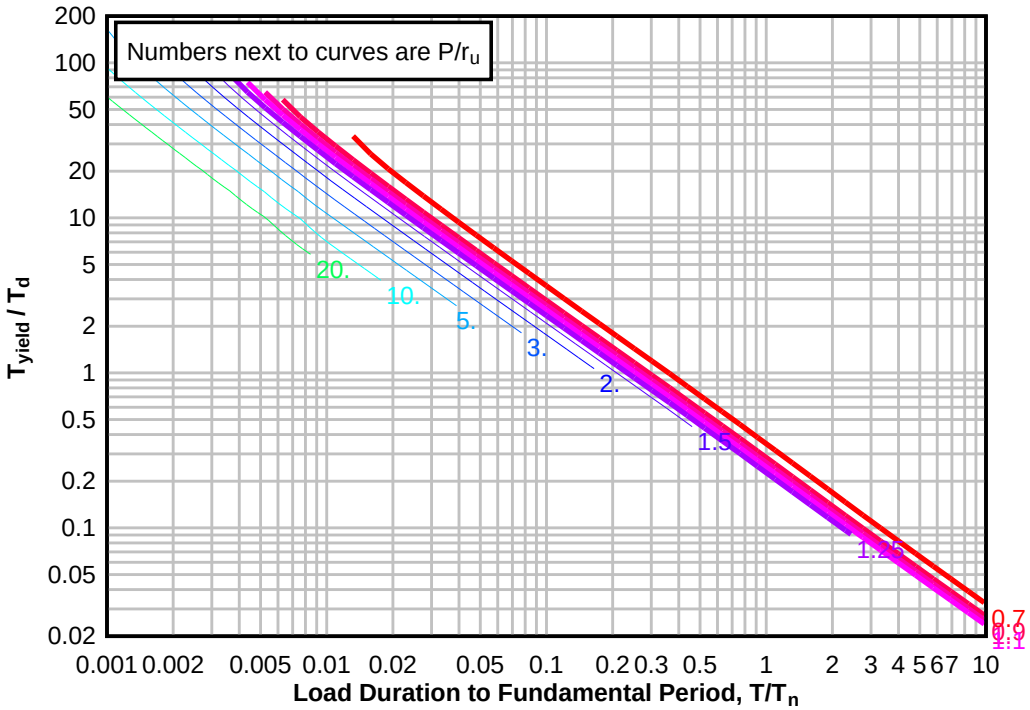


Figure 3-143(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.825, C_2 = 100)

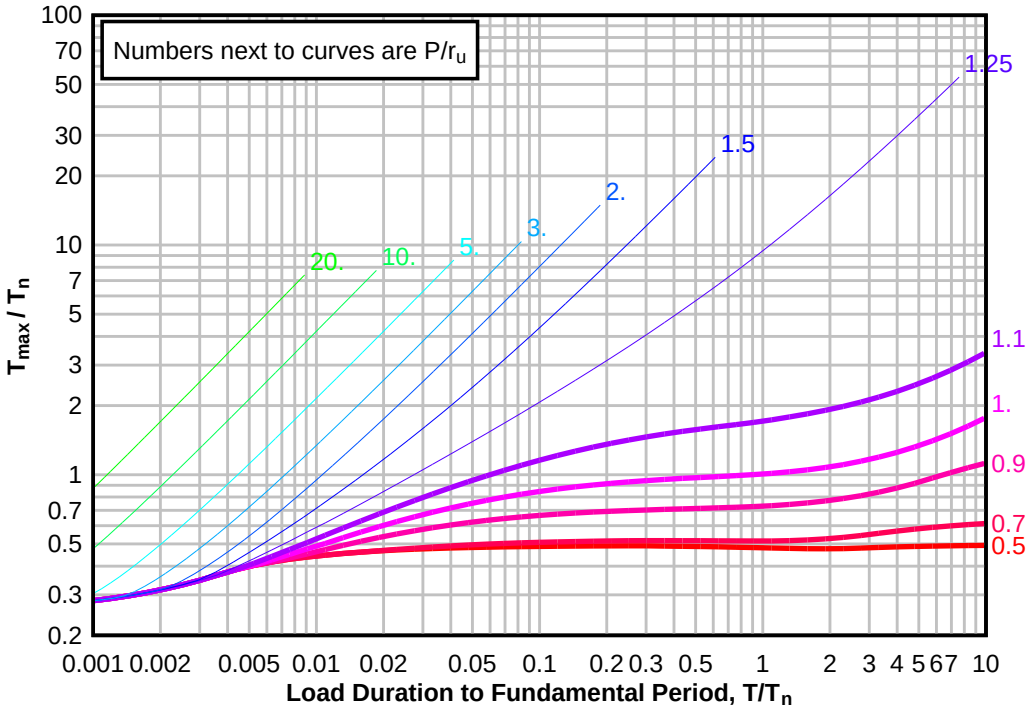


Figure 3-143(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.825, C2 = 100)

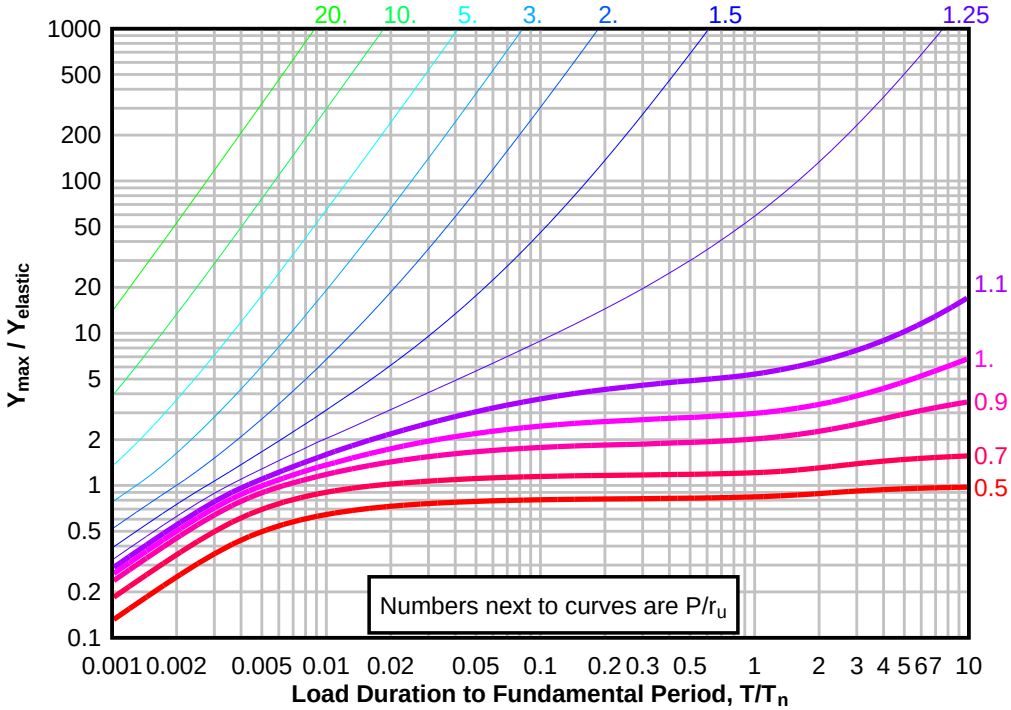


Figure 3-143(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.825, C2 = 100)

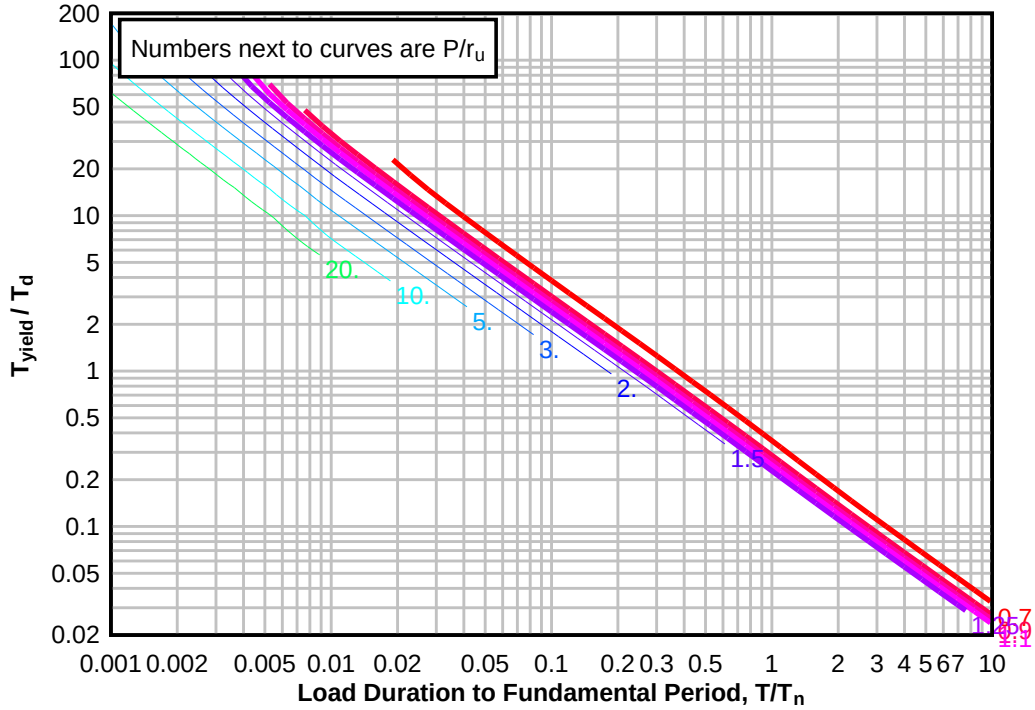


Figure 3-144(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.787, C_2 = 100)

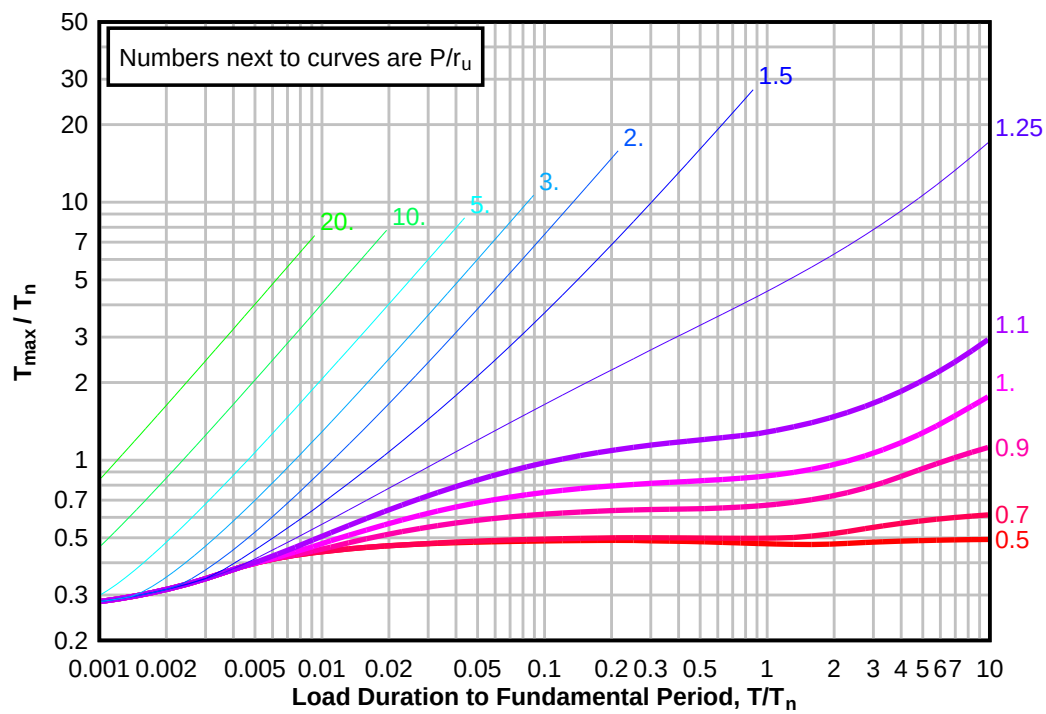


Figure 3-144(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.787, C2 = 100)

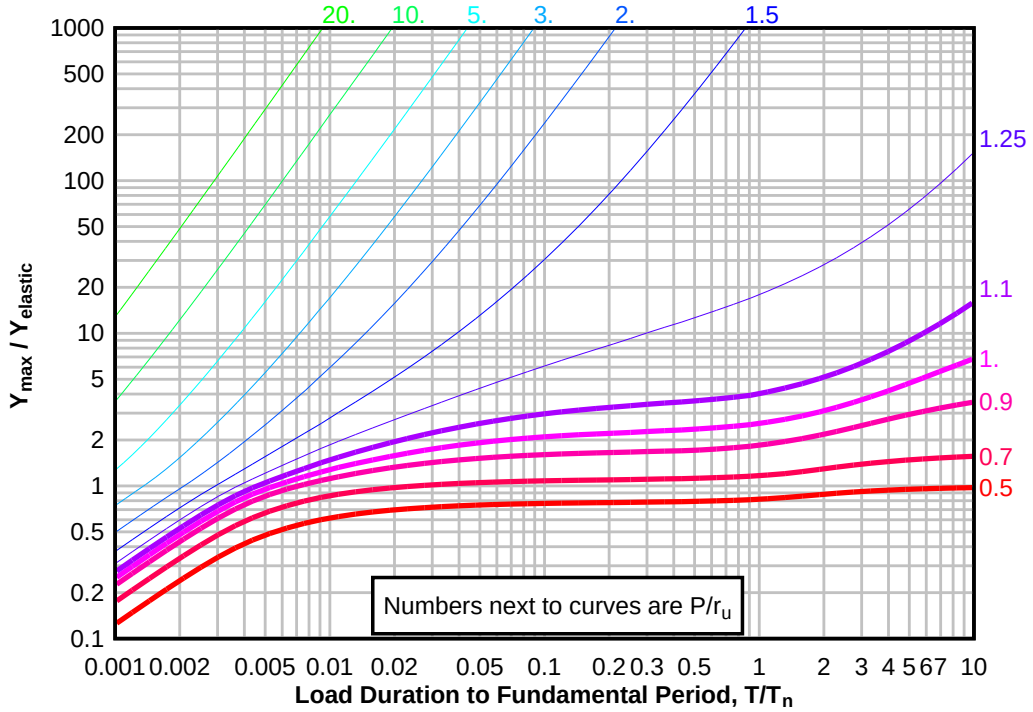


Figure 3-144(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.787, C2 = 100)

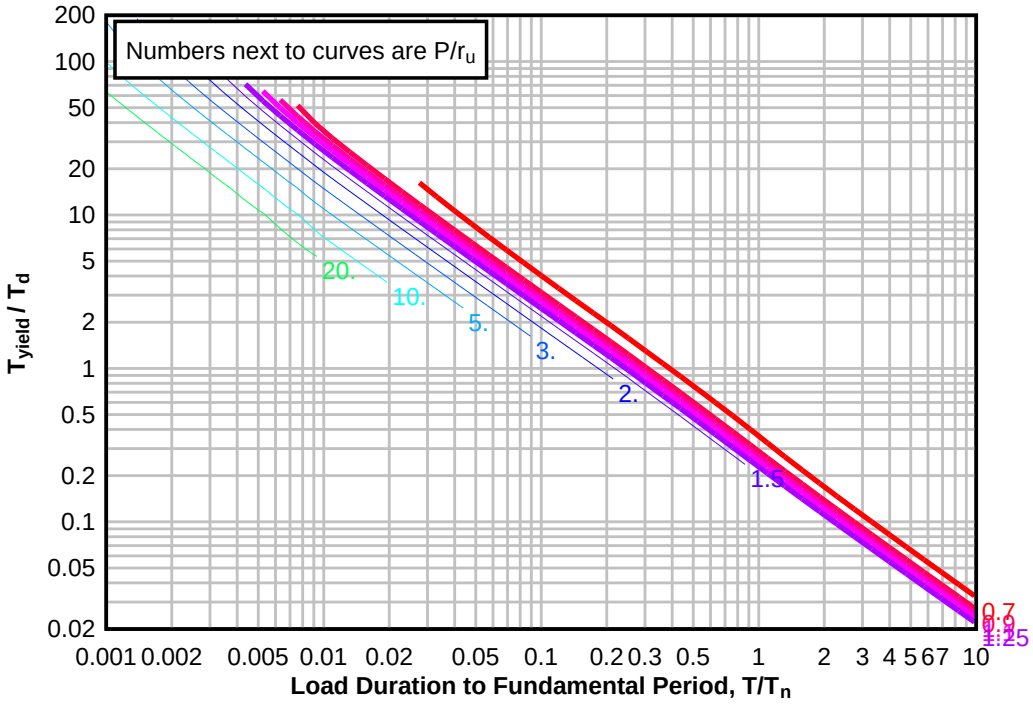


Figure 3-145(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.750, C_2 = 100)

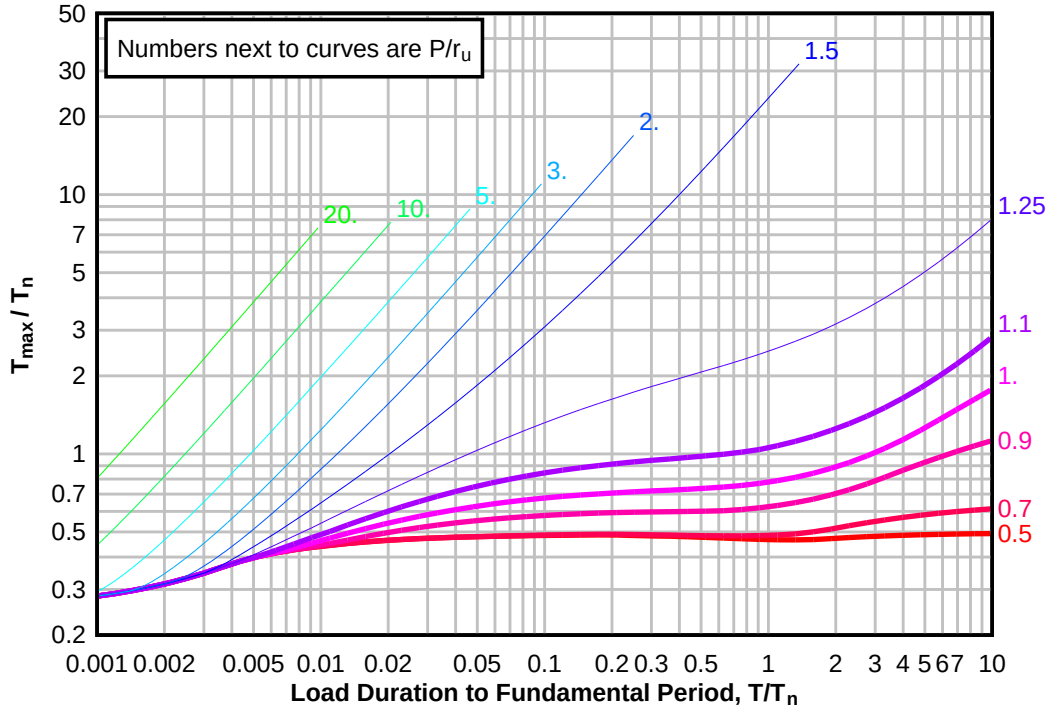


Figure 3-145(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.750, C2 = 100)

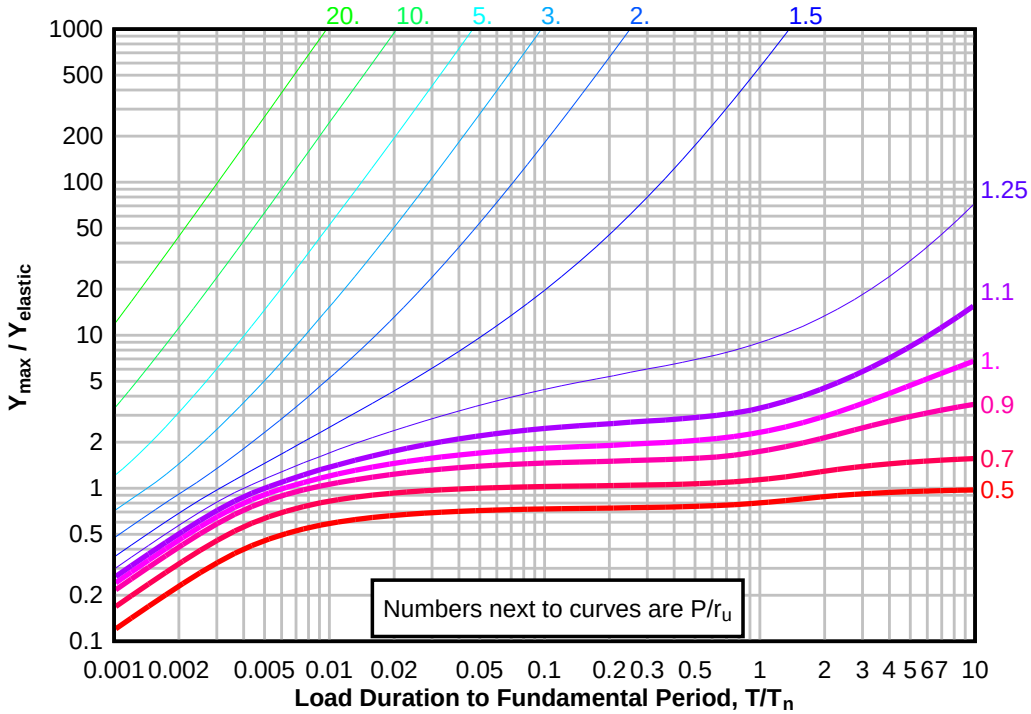


Figure 3-145(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.750, C2 = 100)

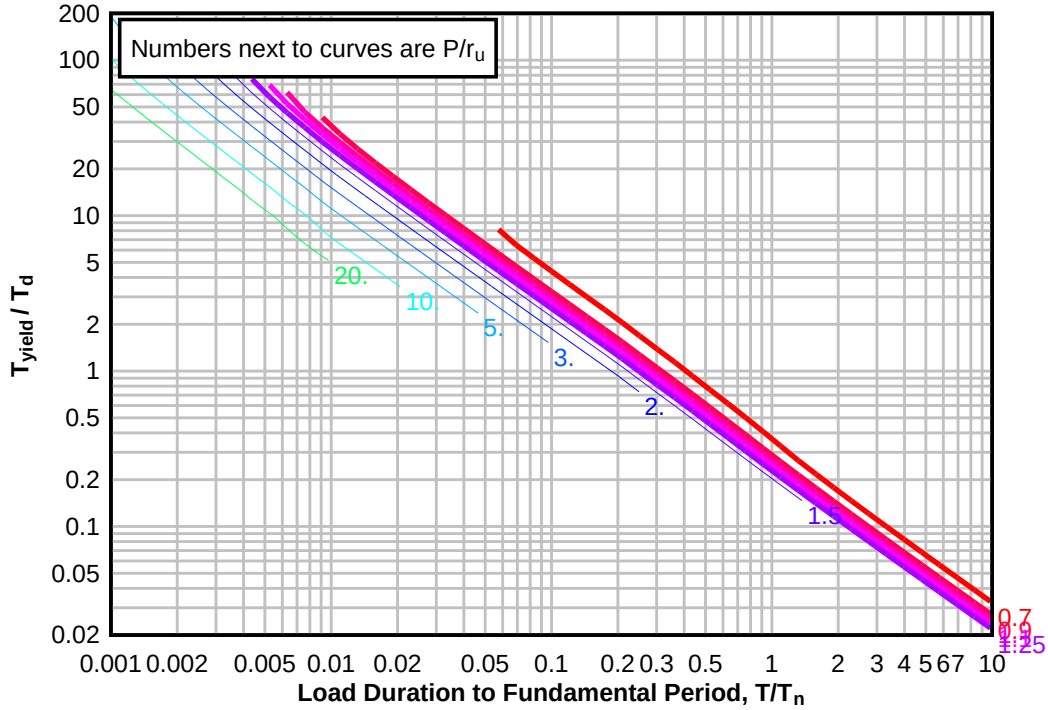


Figure 3-146(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.715, C_2 = 100)

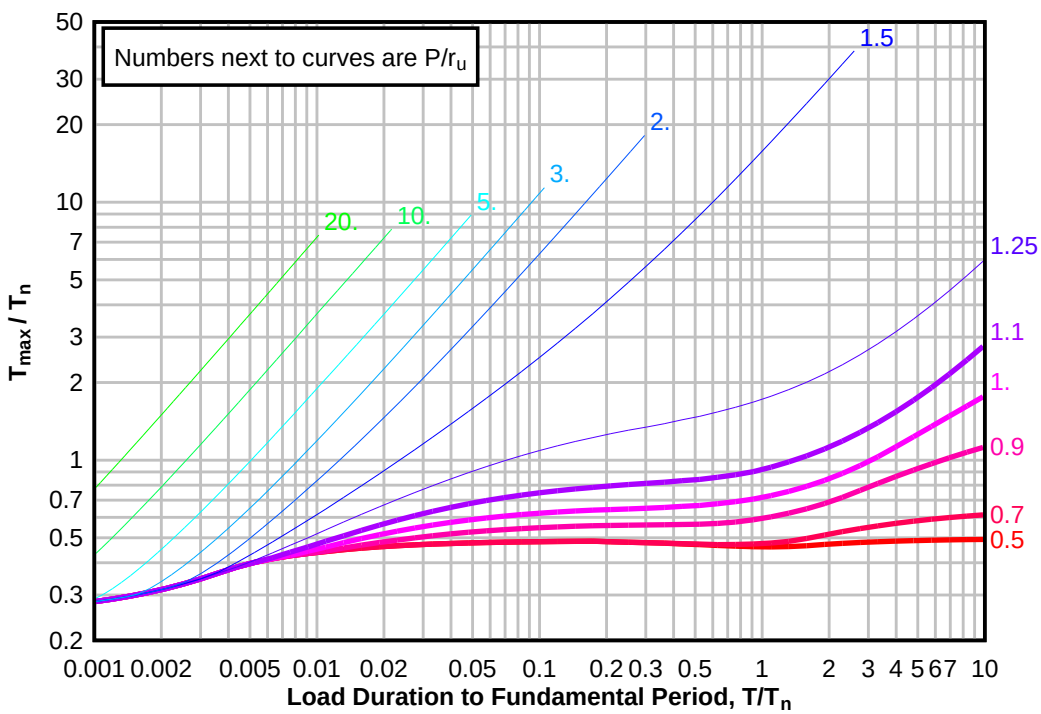


Figure 3-146(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.715, C2 = 100)

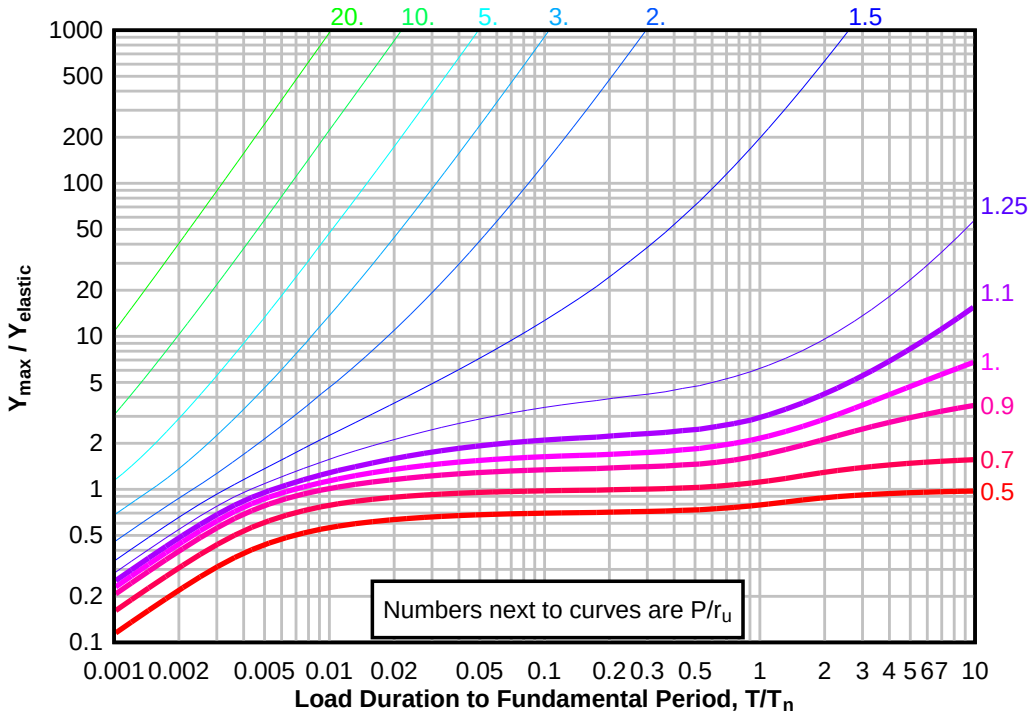


Figure 3-146(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.715, C2 = 100)

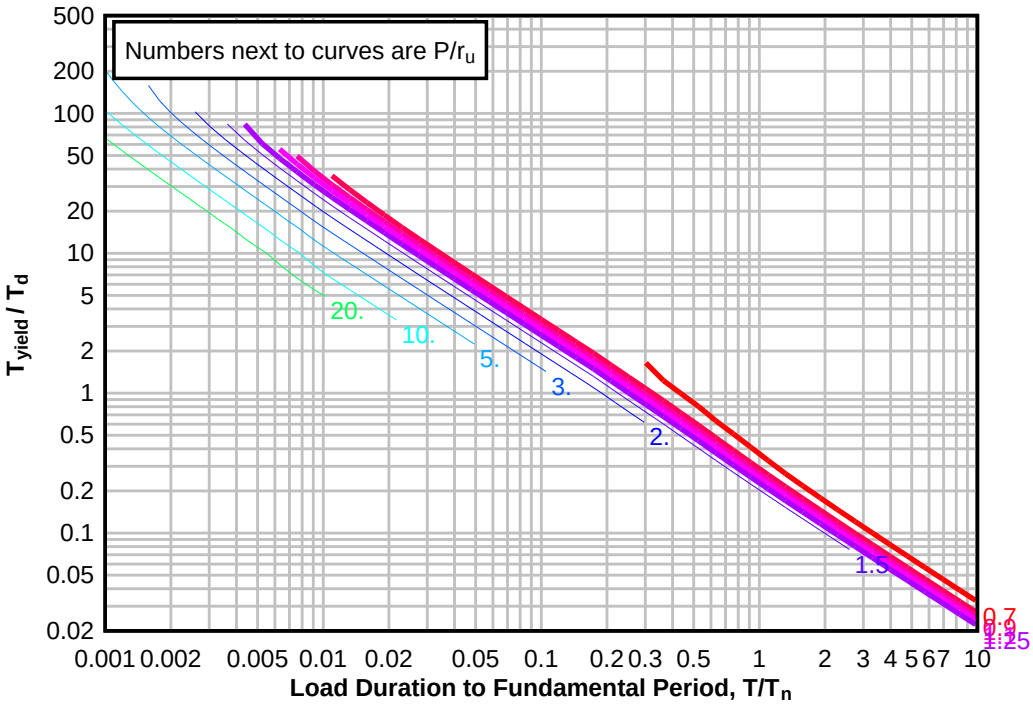


Figure 3-147(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.681, C_2 = 100)

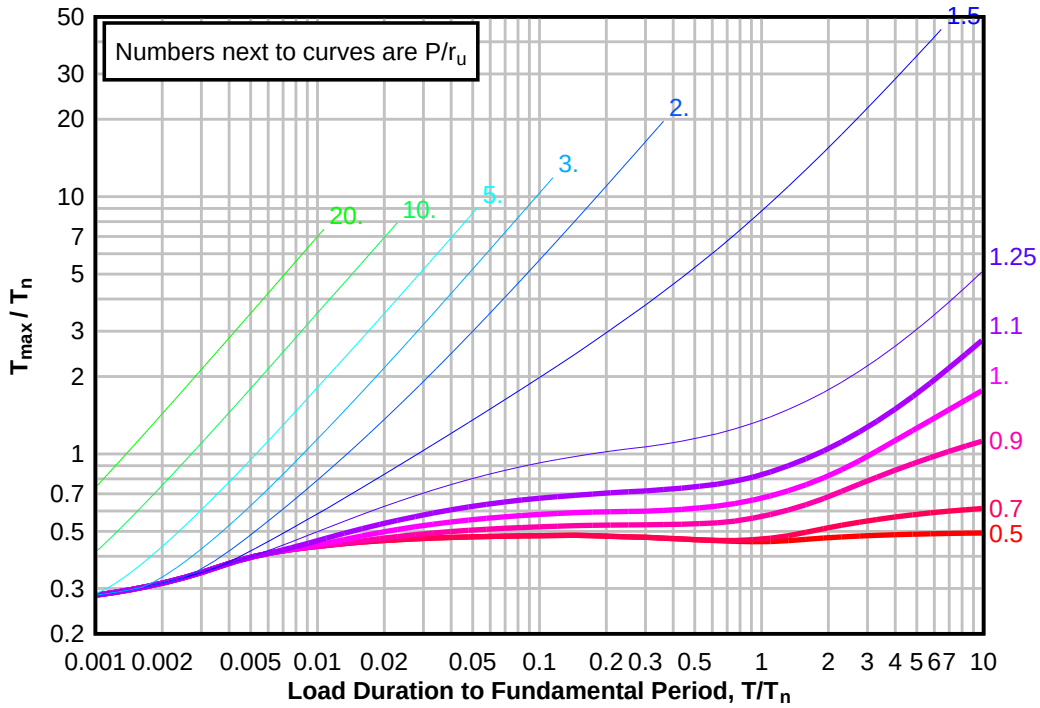


Figure 3 147(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.681, C2 = 100)

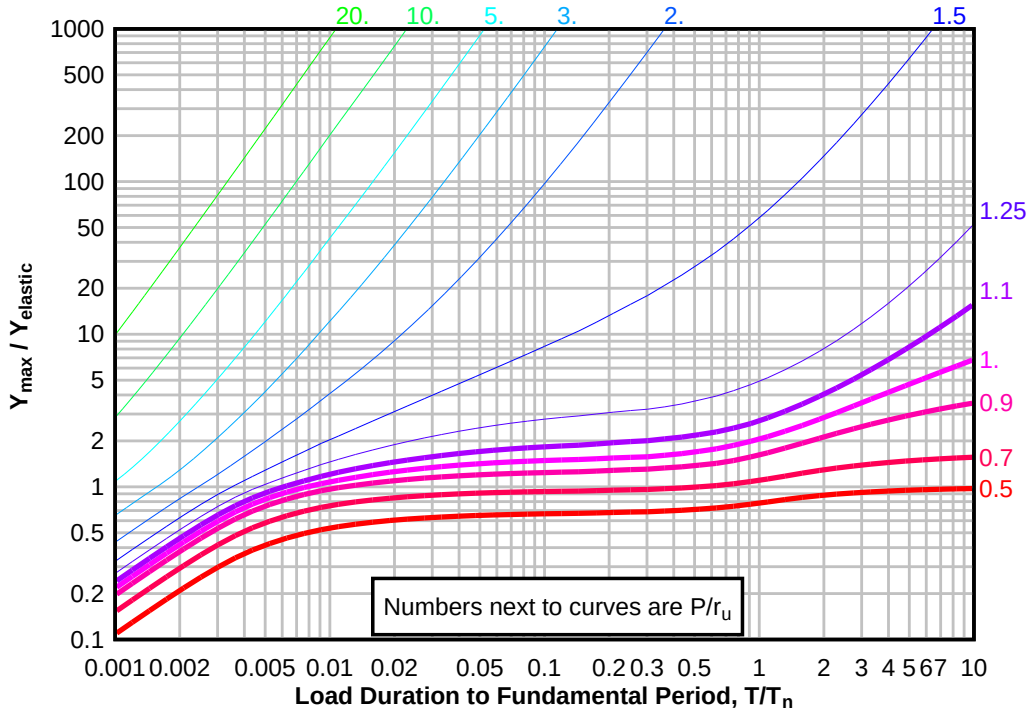


Figure 3-147(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.681, C2 = 100)

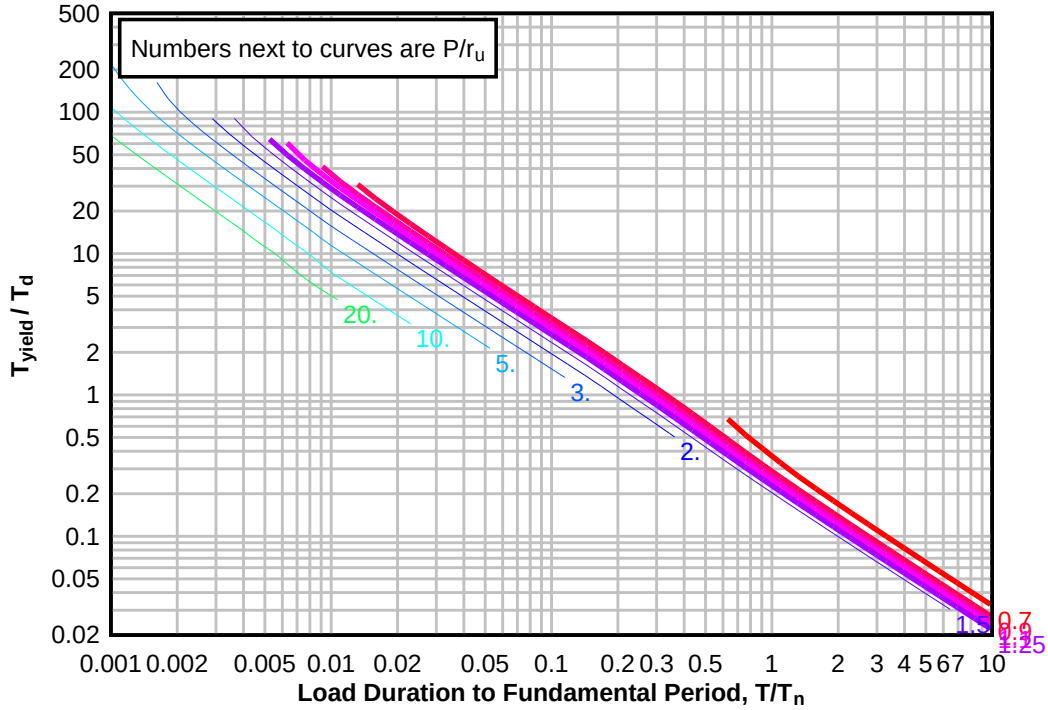


Figure 3-148(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.648, C_2 = 100)

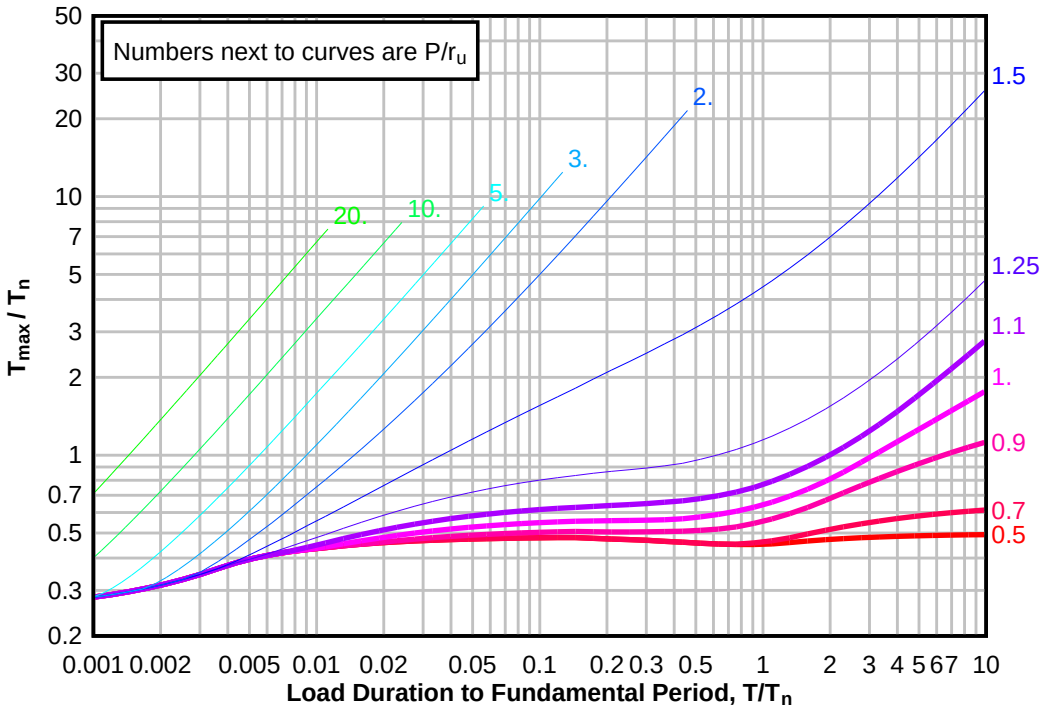


Figure 3-148(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.648, C2 = 100)

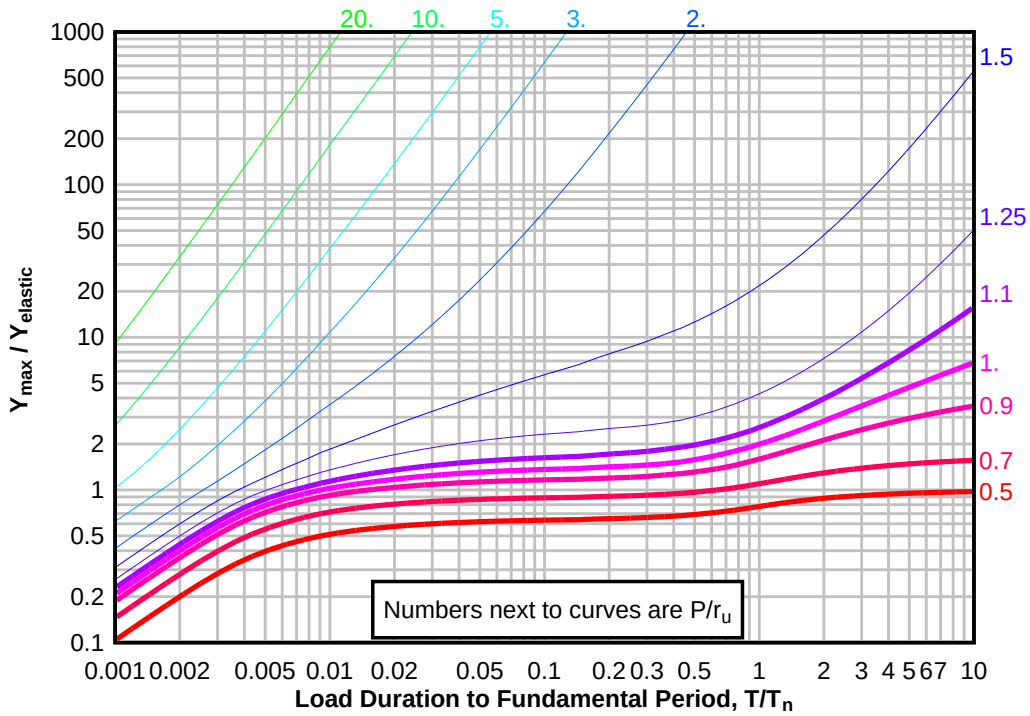


Figure 3-148(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.648, C2 = 100)

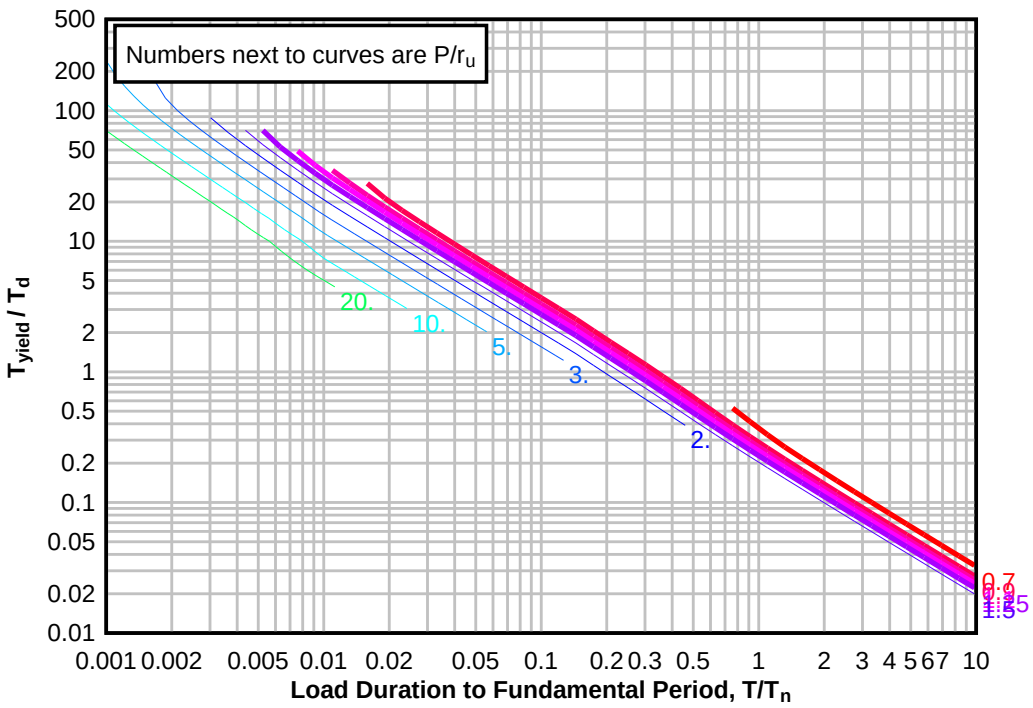


Figure 3-149(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.619, C_2 = 100)

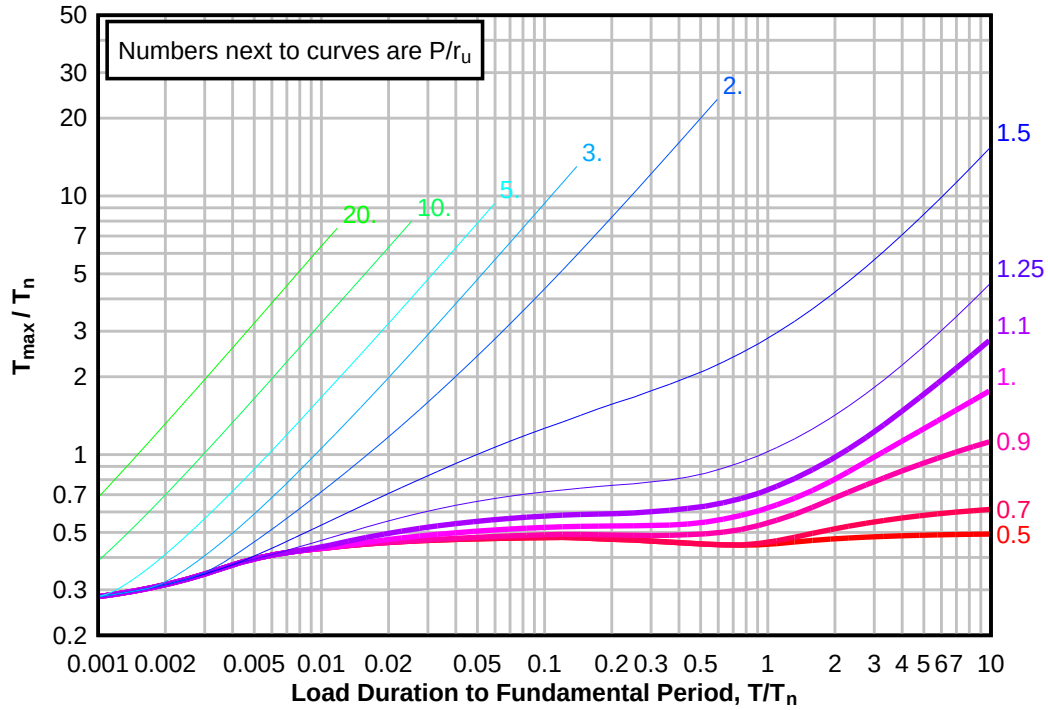


Figure 3-149(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.619, C2 = 100)

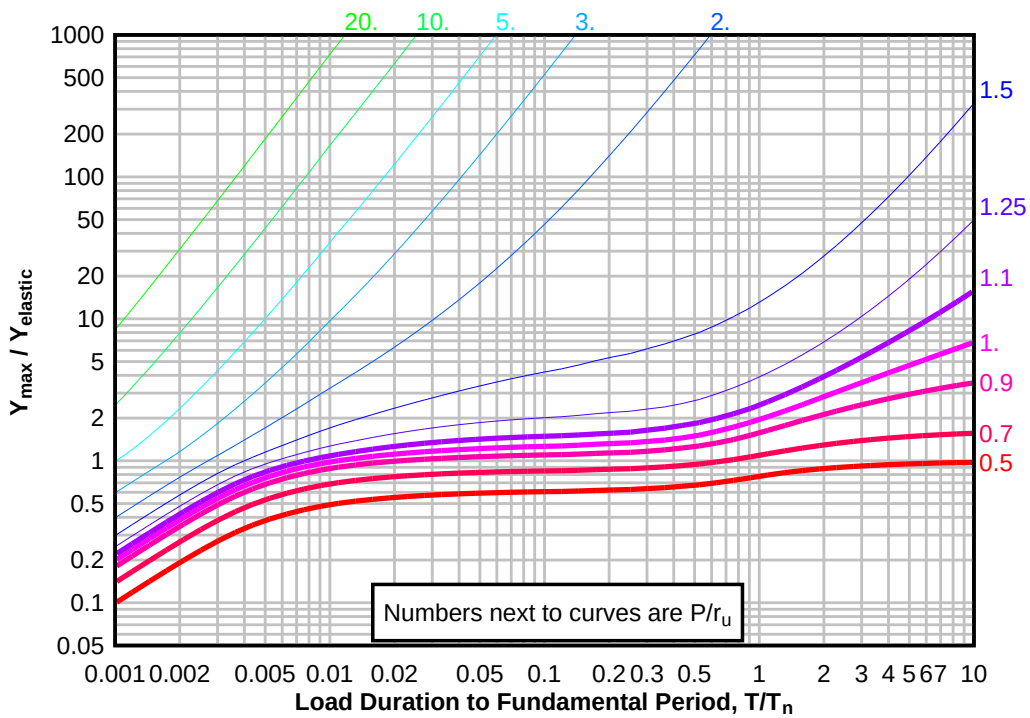


Figure 3-149(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.619, C2 = 100)

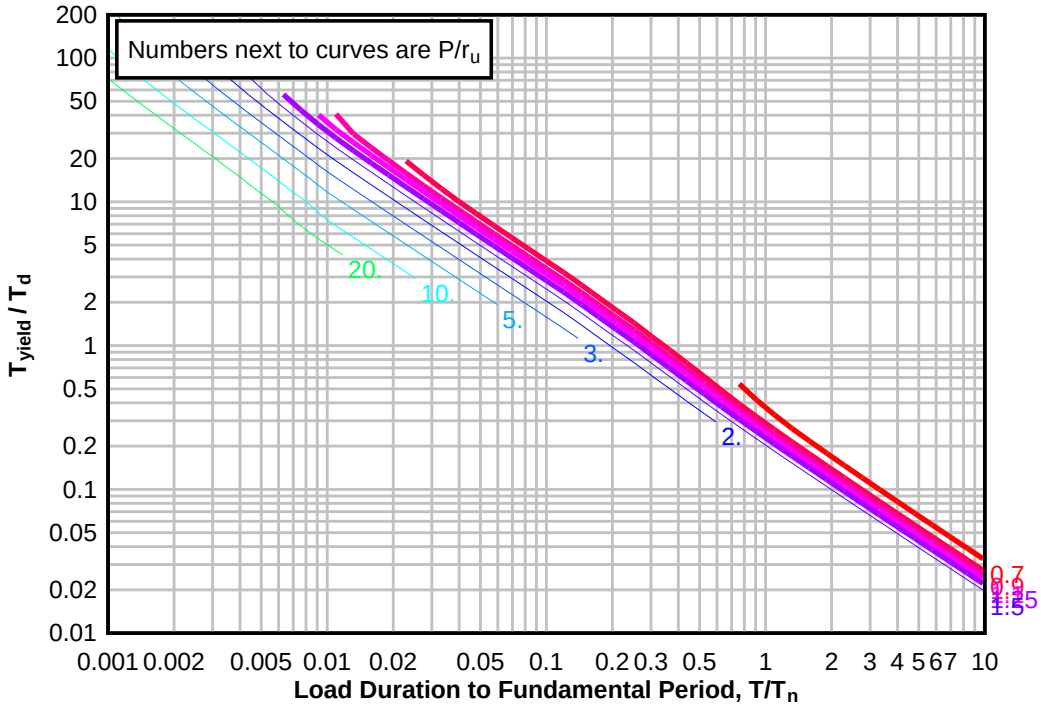


Figure 3-150(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.590, C_2 = 100)

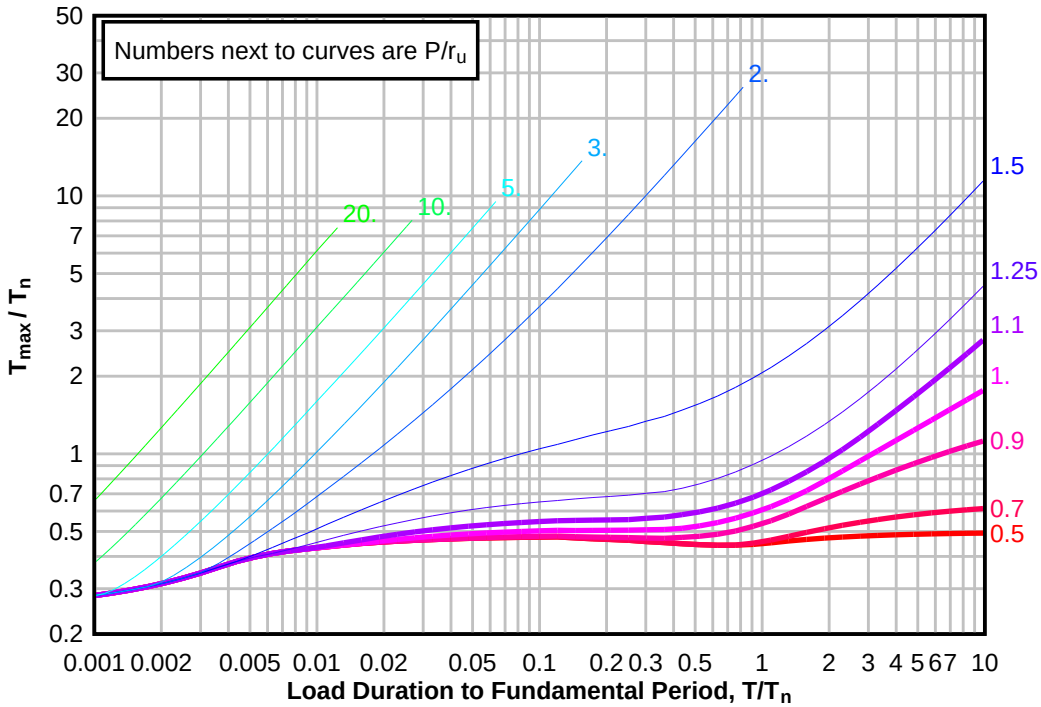


Figure 3-150(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.590, C2 = 100)

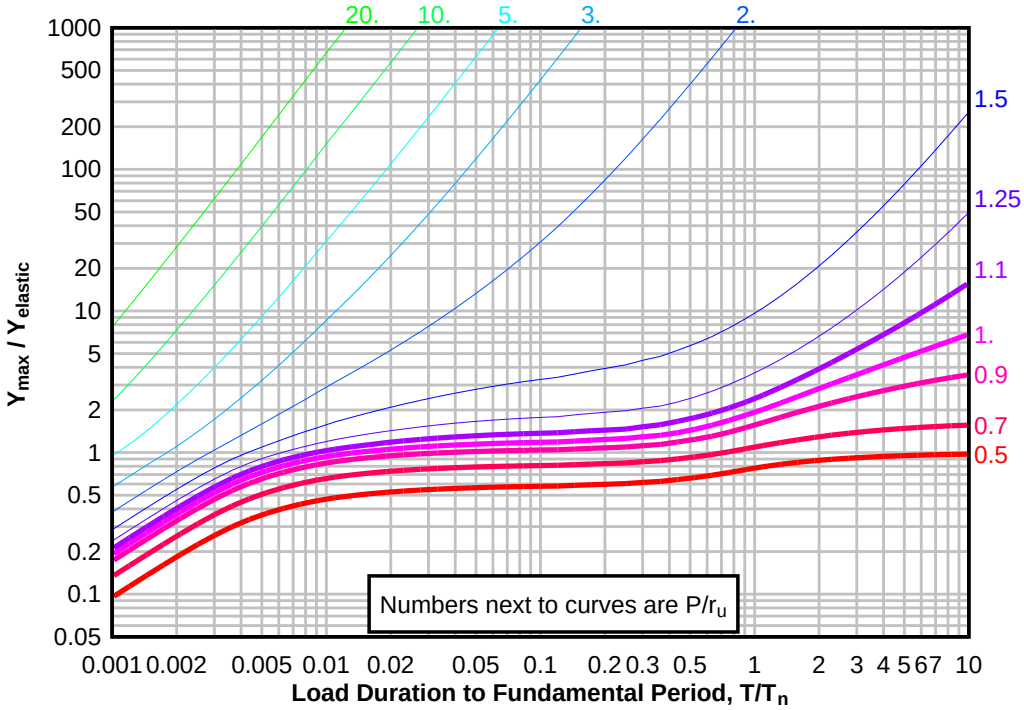


Figure 3-150(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.590, C2 = 100)

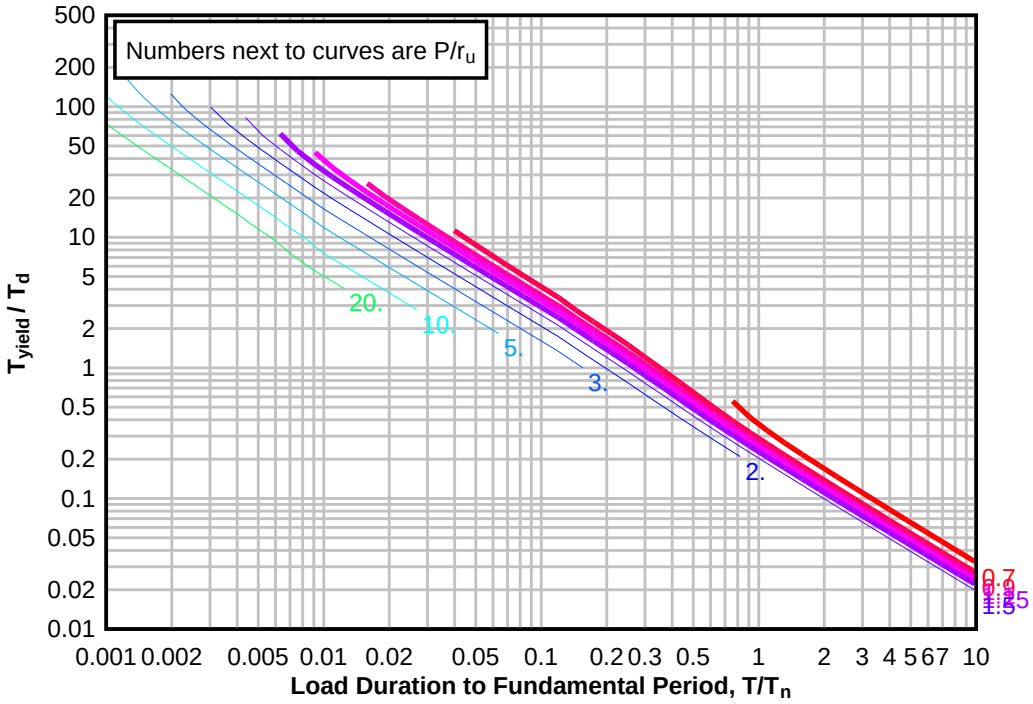


Figure 3-151(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.562, C_2 = 100)

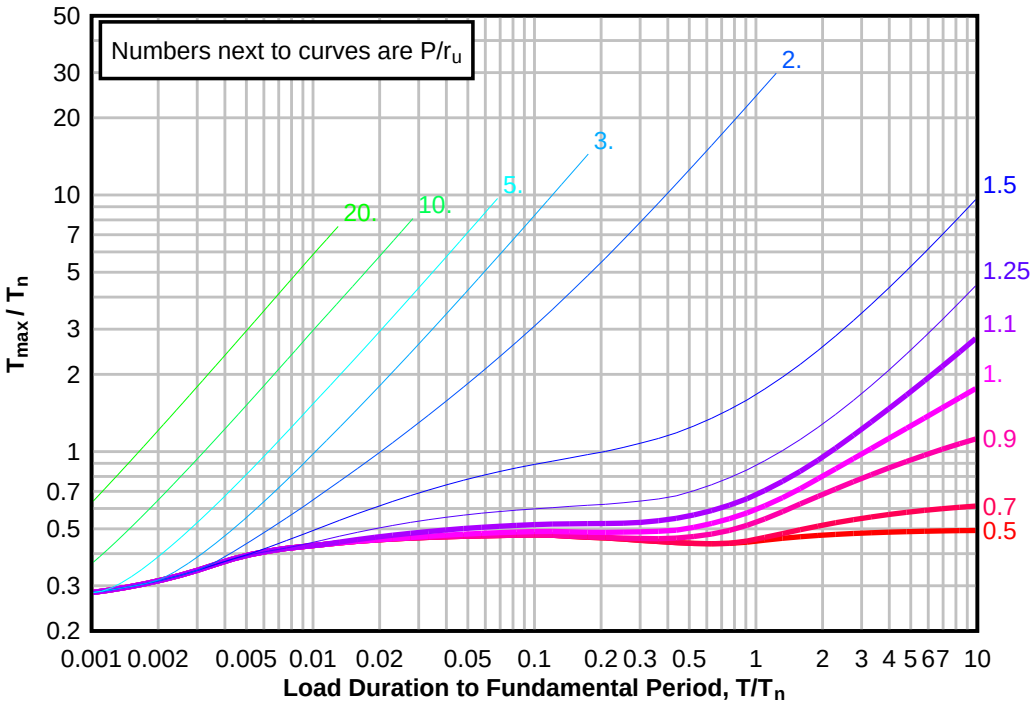


Figure 3-151(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.562, C2 = 100)

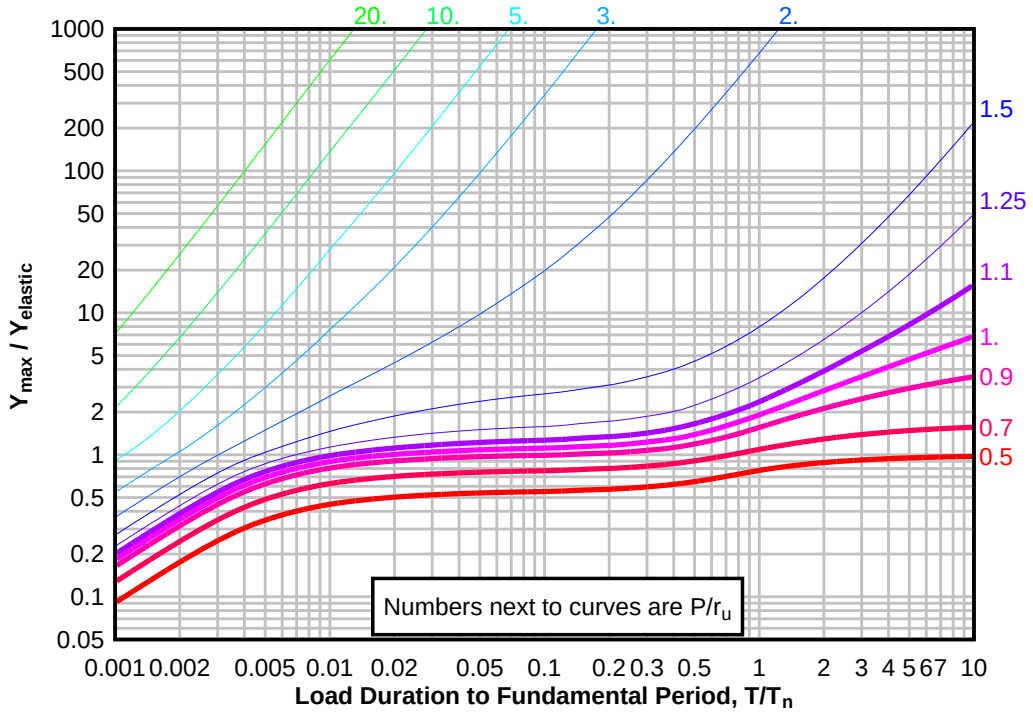


Figure 3-151(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.562, C2 = 100)

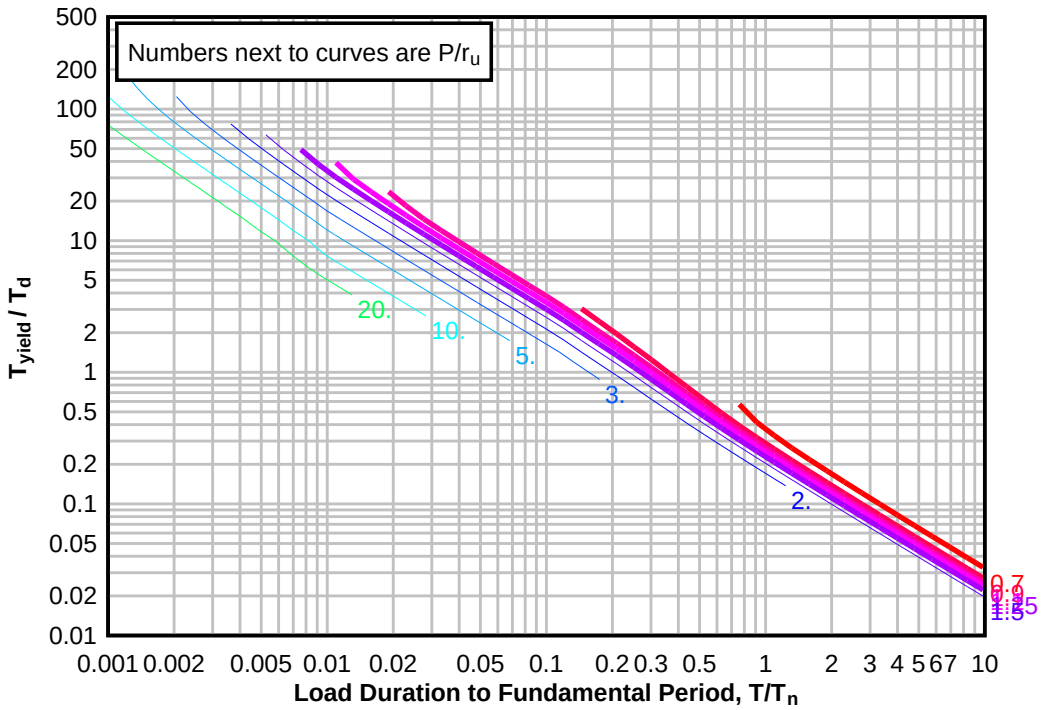


Figure 3-152(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.511, C_2 = 100)

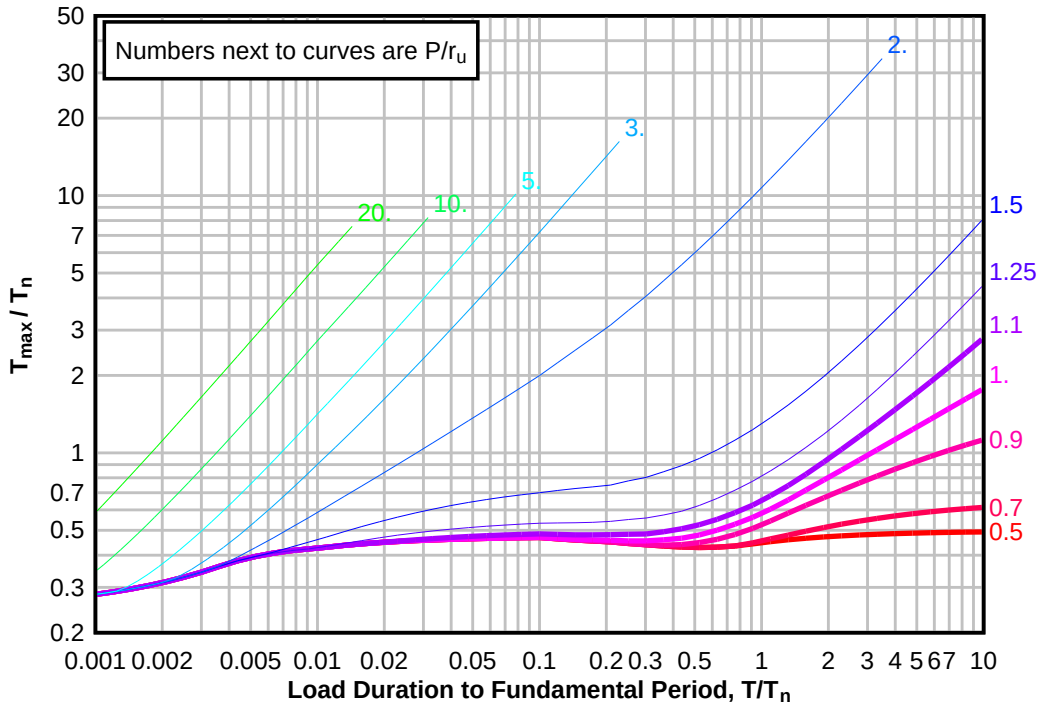


Figure 3-152(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.511, C2 = 100)

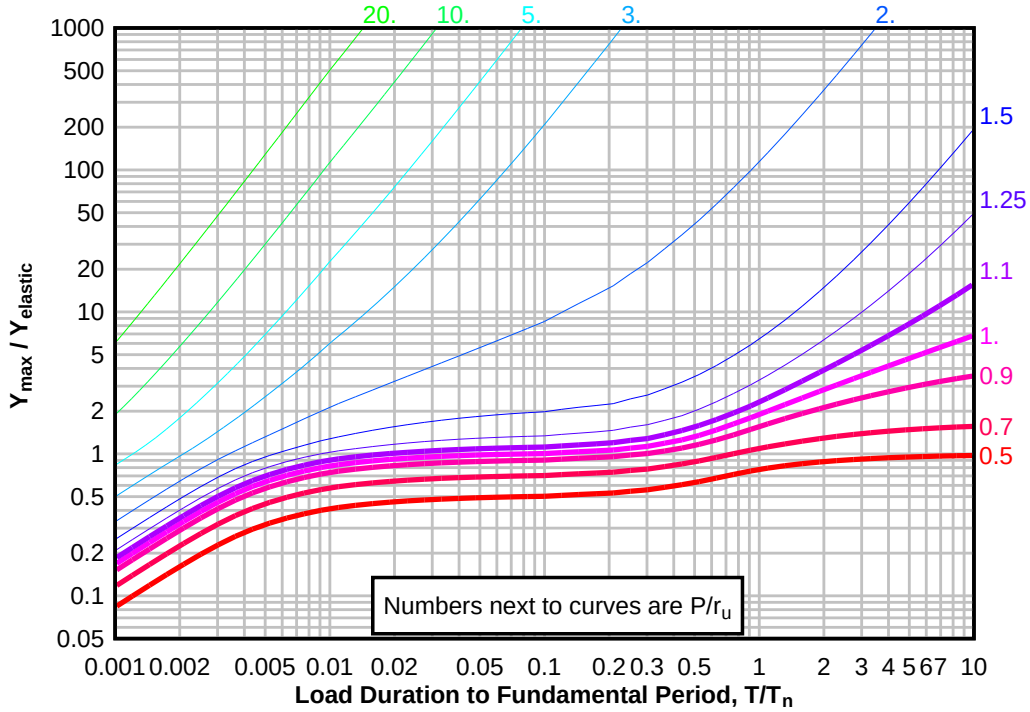


Figure 3-152(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.511, C2 = 100)

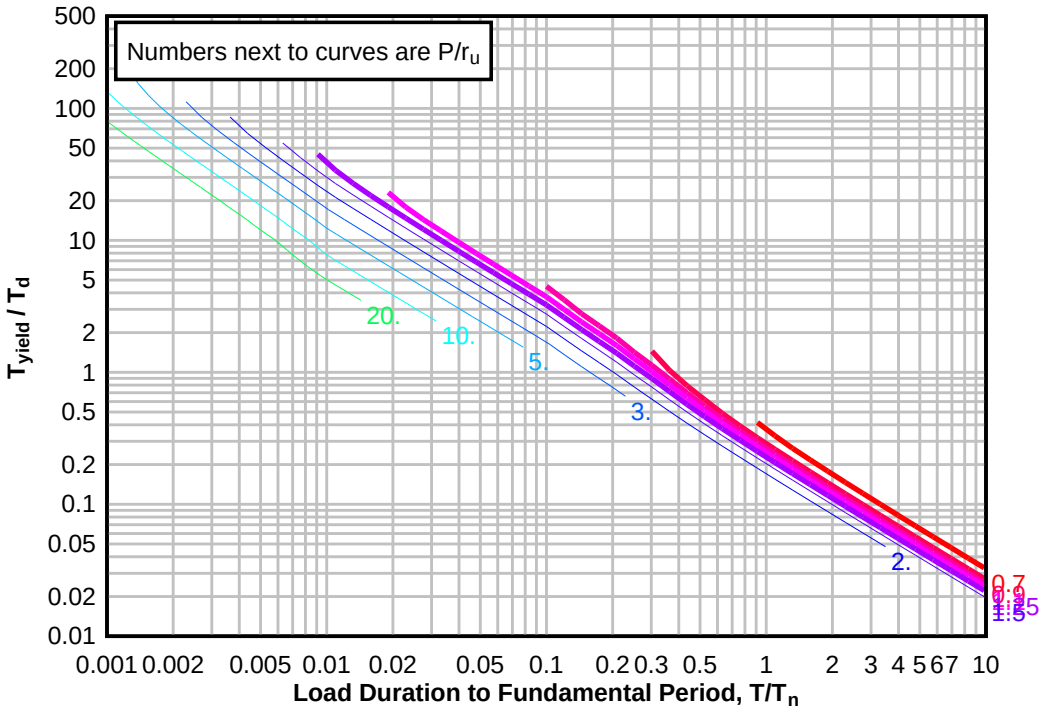


Figure 3-153(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.464, C_2 = 100)

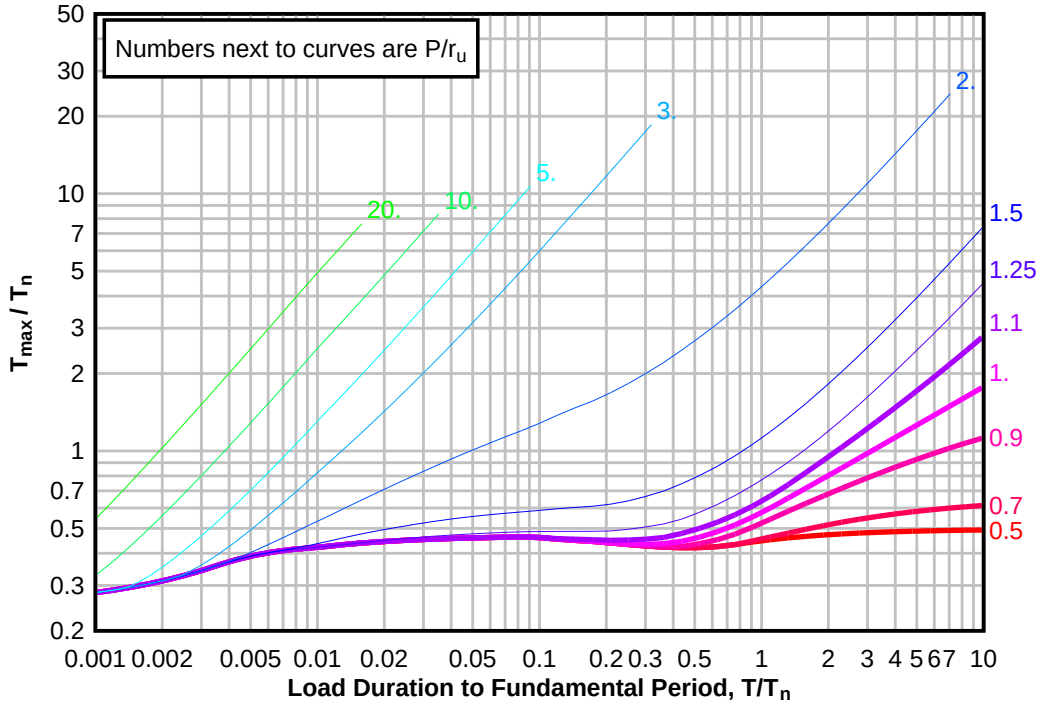


Figure 3-153(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.464, C2 = 100)

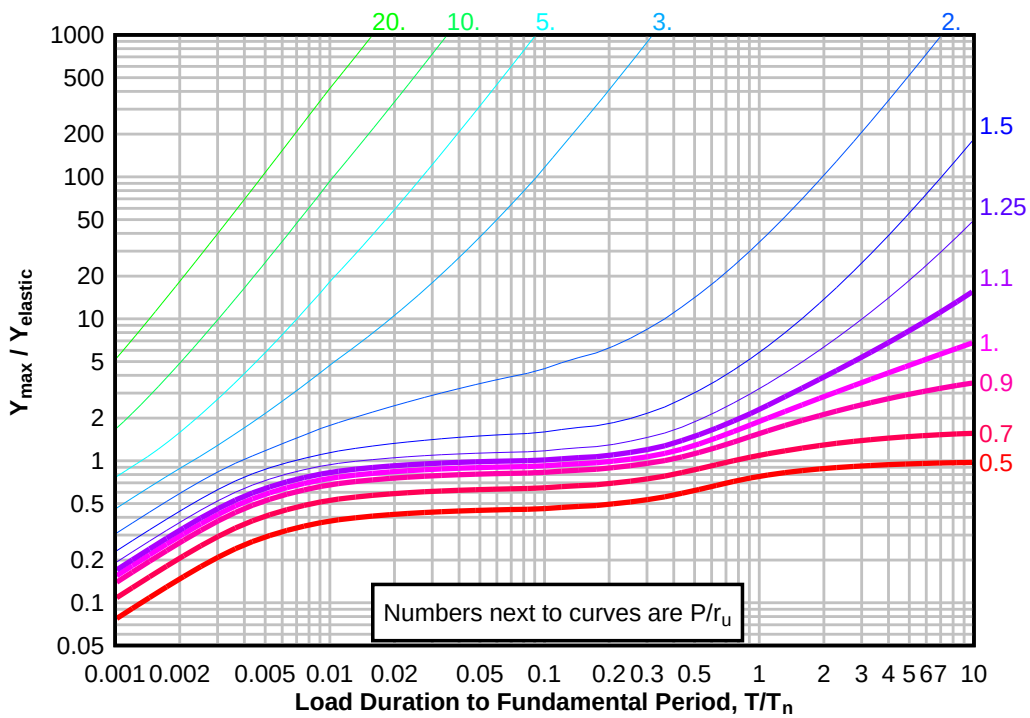


Figure 3-153(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.464, C2 = 100)

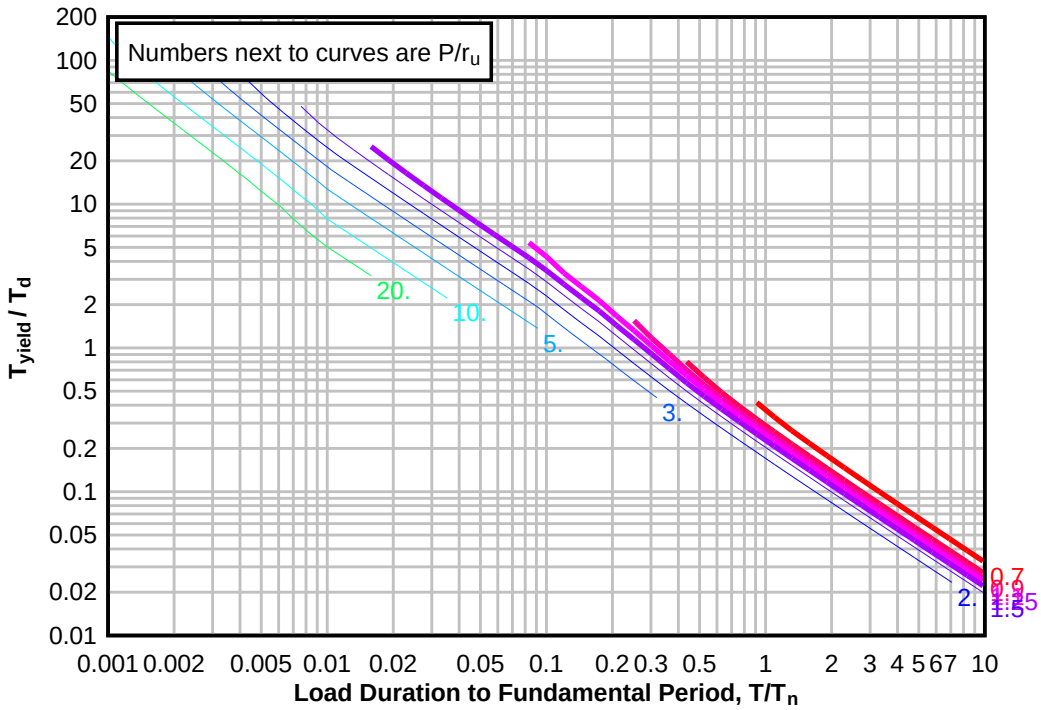


Figure 3-154(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.422, C_2 = 100)

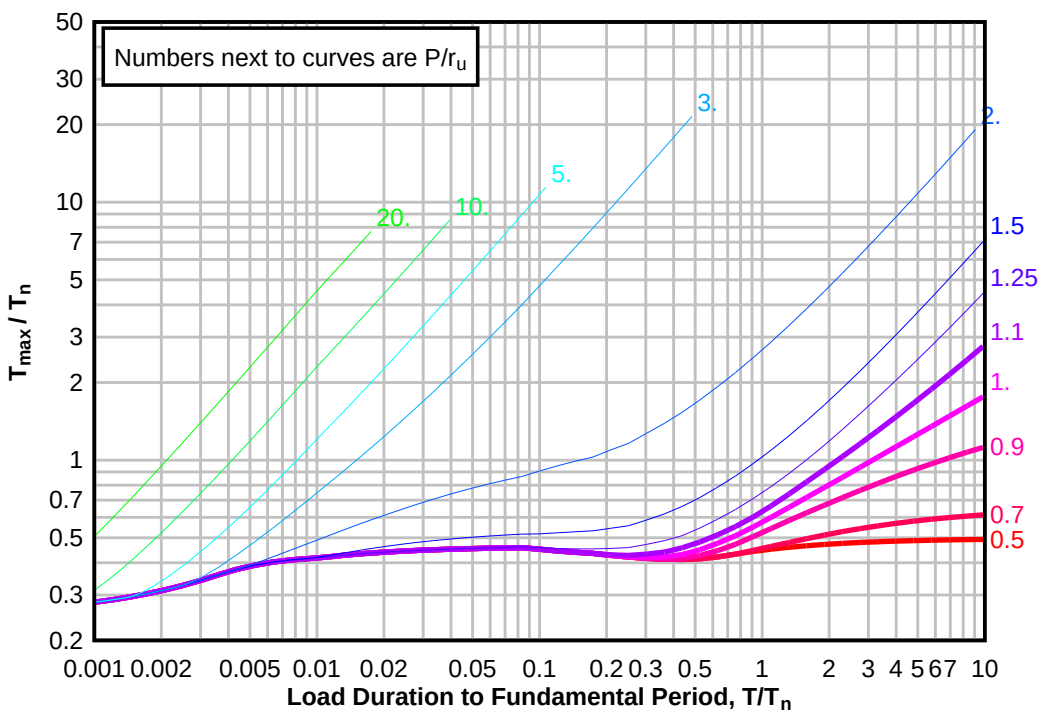


Figure 3-154(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.422, C2 = 100)

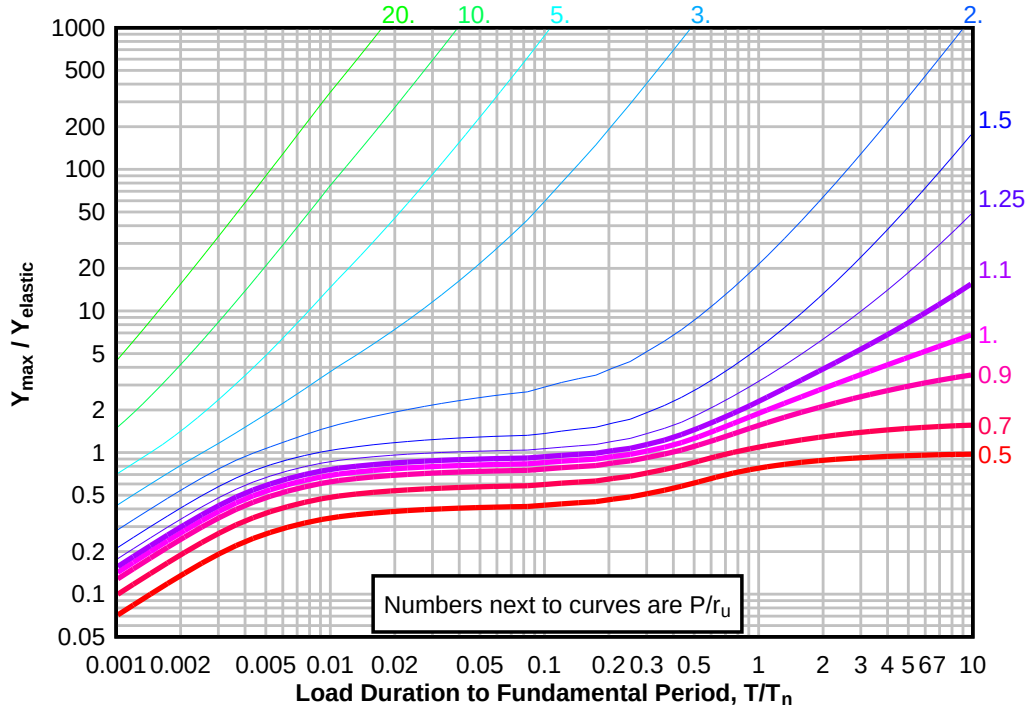


Figure 3-154(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.422, C2 = 100)

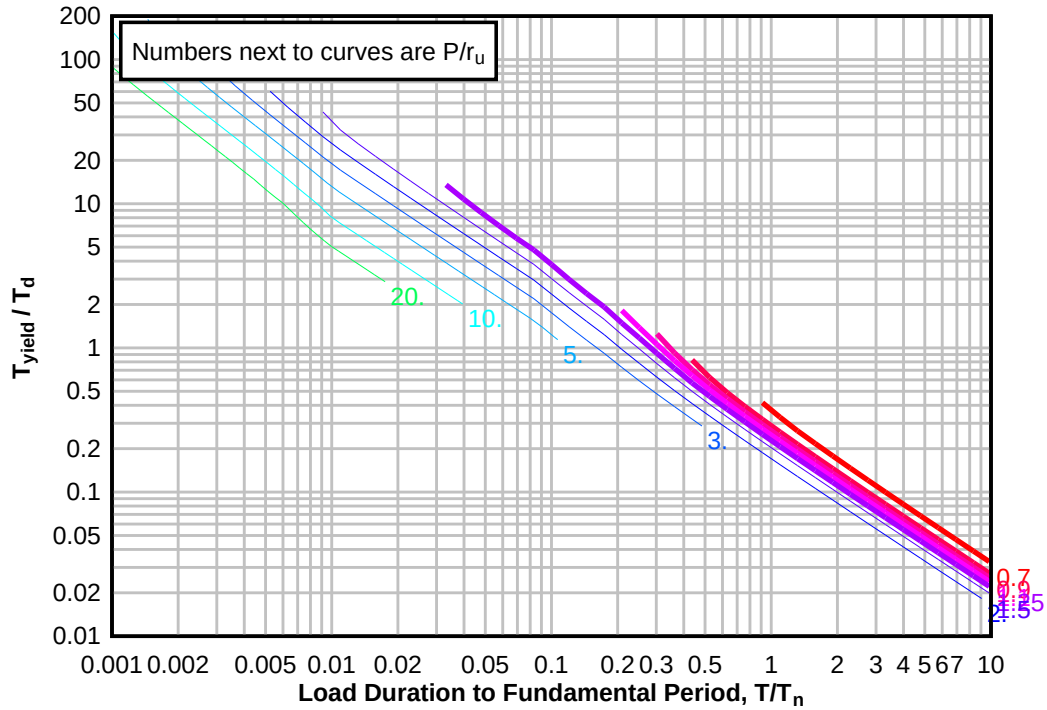


Figure 3-155(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.365, C_2 = 100)

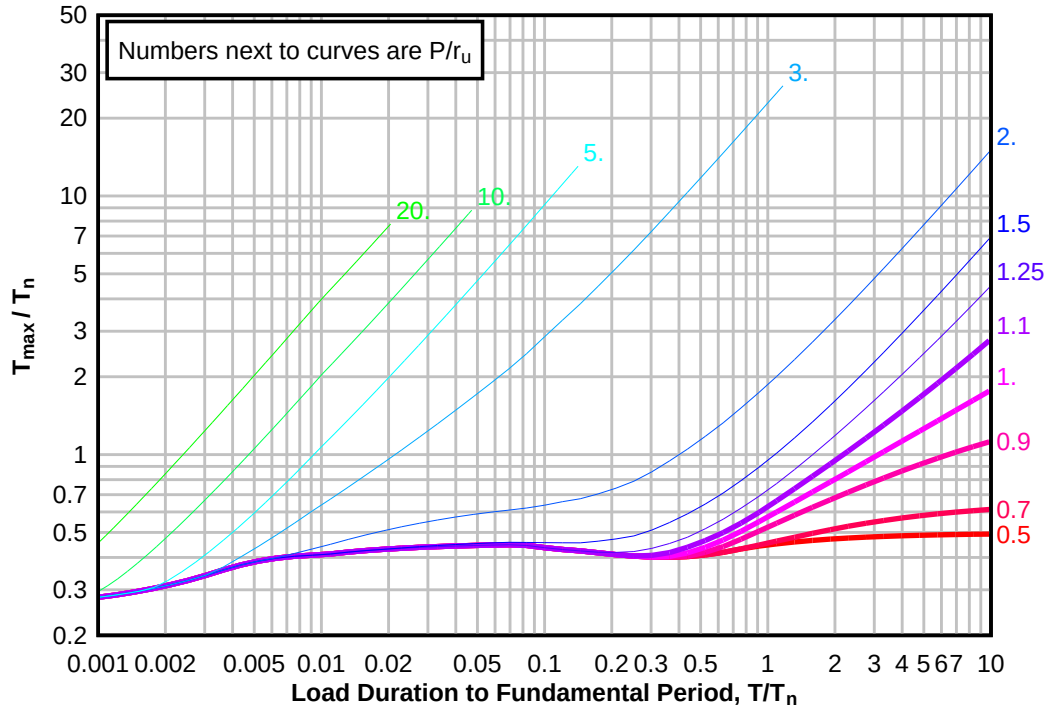


Figure 3-155(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.365, C2 = 100)

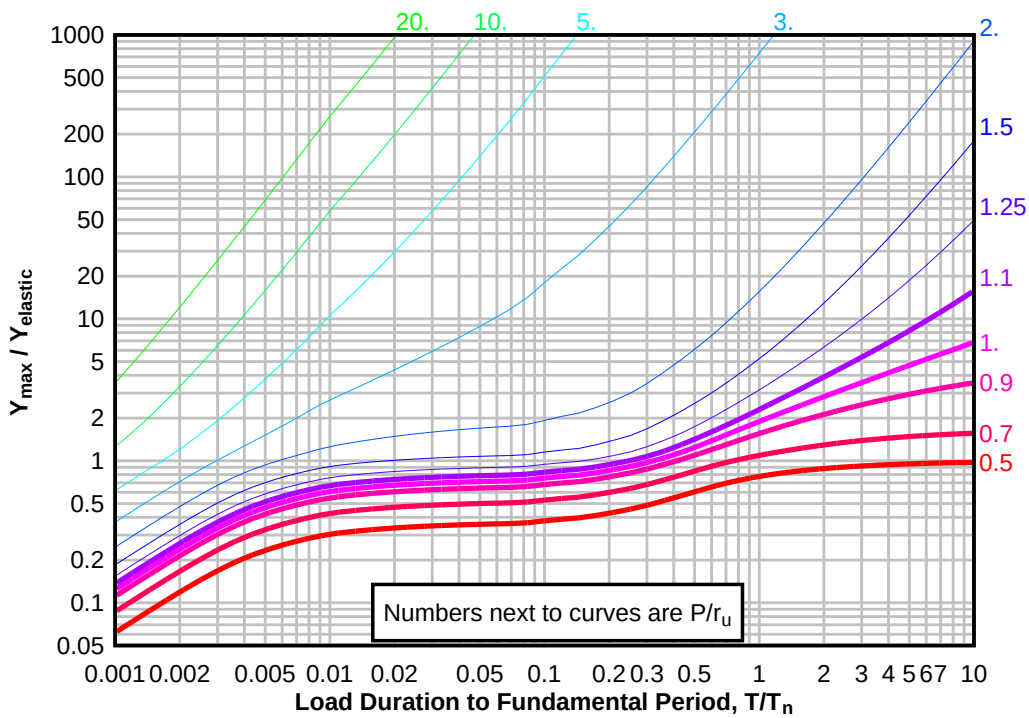


Figure 3-155(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.365, C2 = 100)

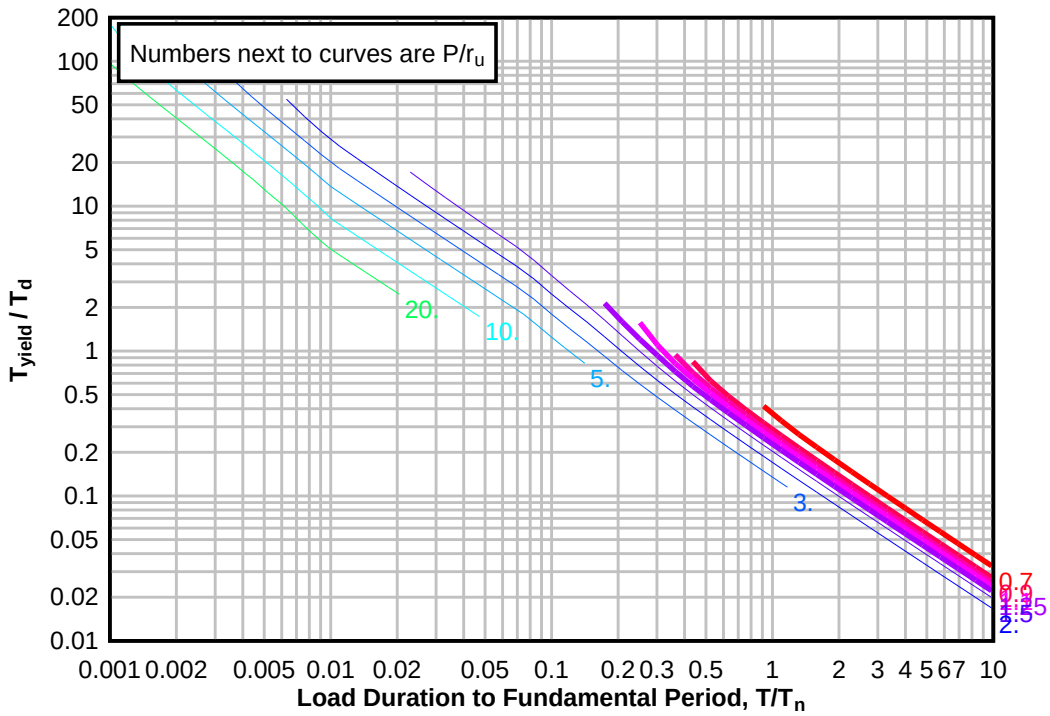


Figure 3-156(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.316, C_2 = 100)

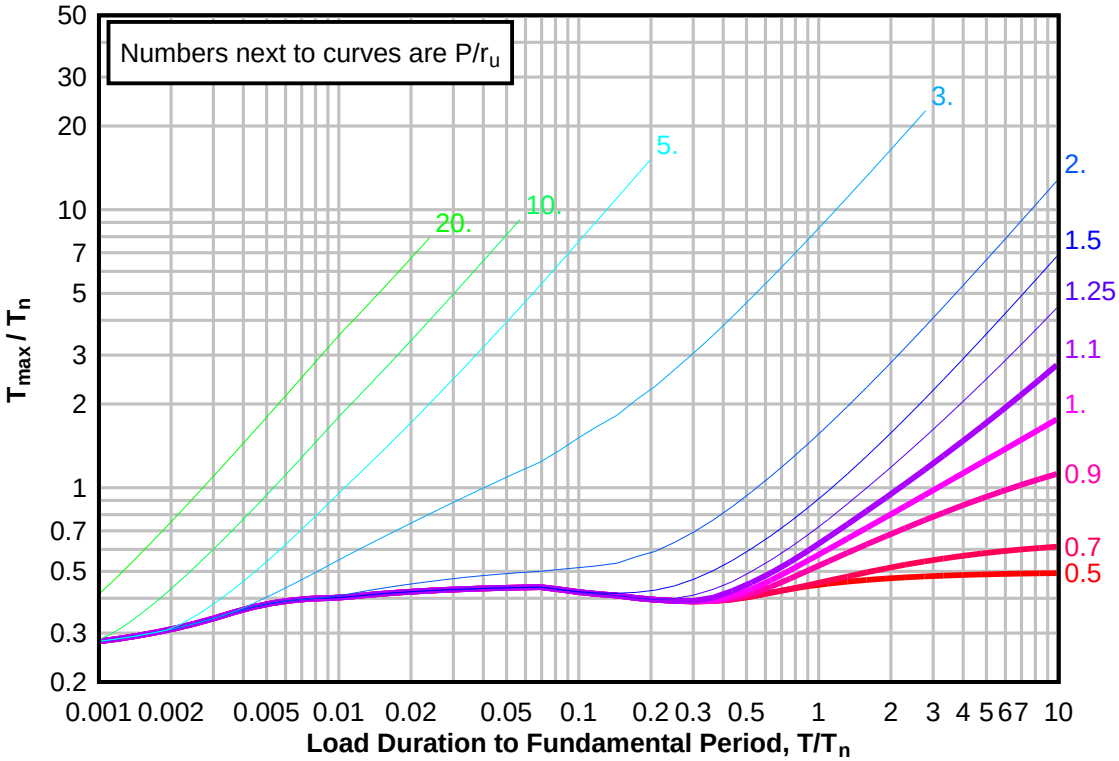


Figure 3-156(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.316, C2 = 100)

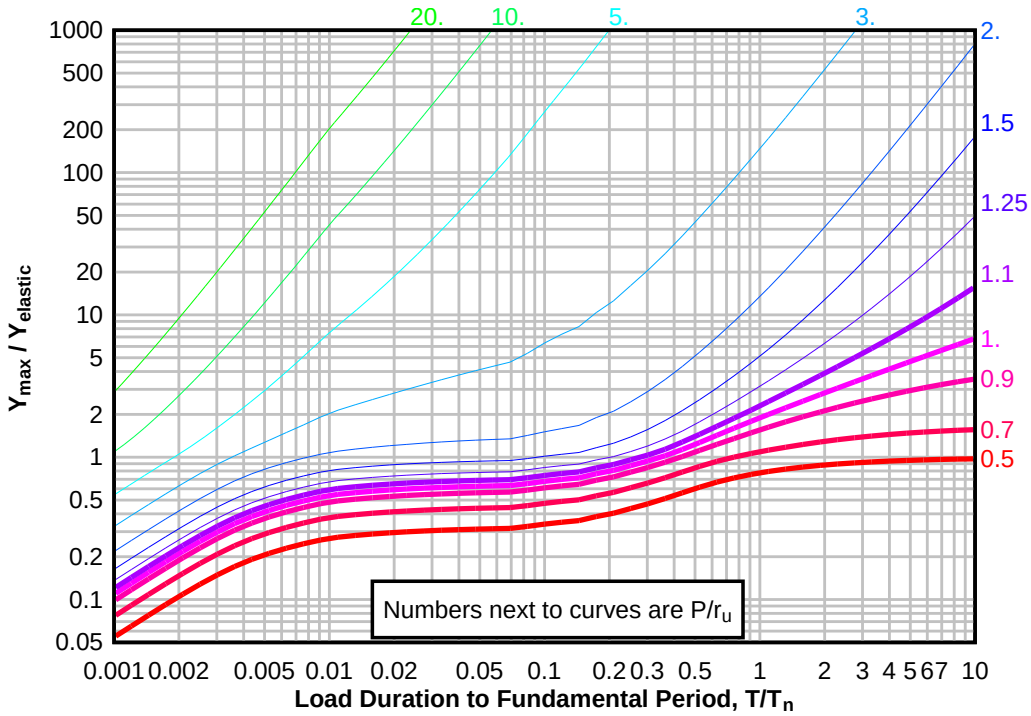


Figure 3-156(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.316, C2 = 100)

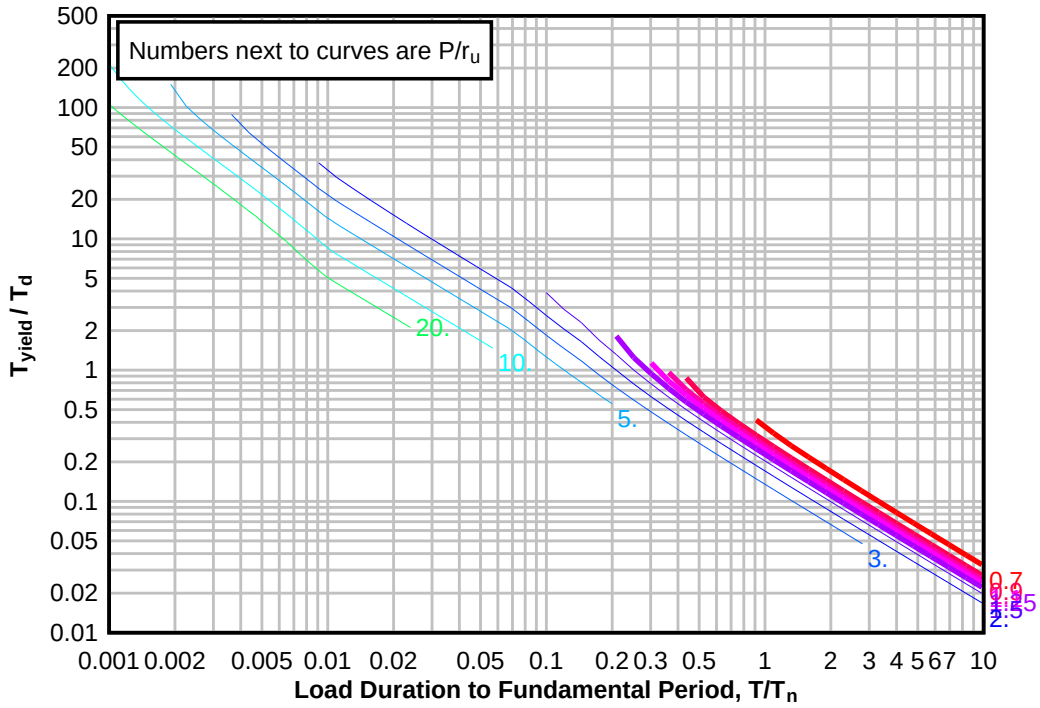


Figure 3-157(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.274, C_2 = 100)

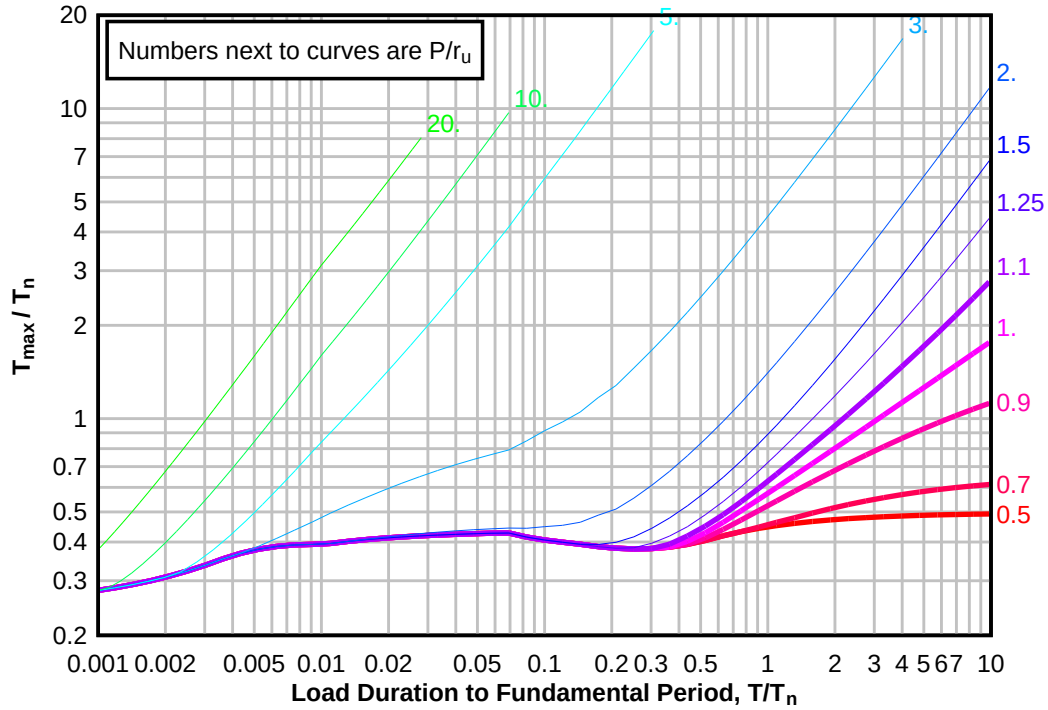


Figure 3-157(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.274, C2 = 100)

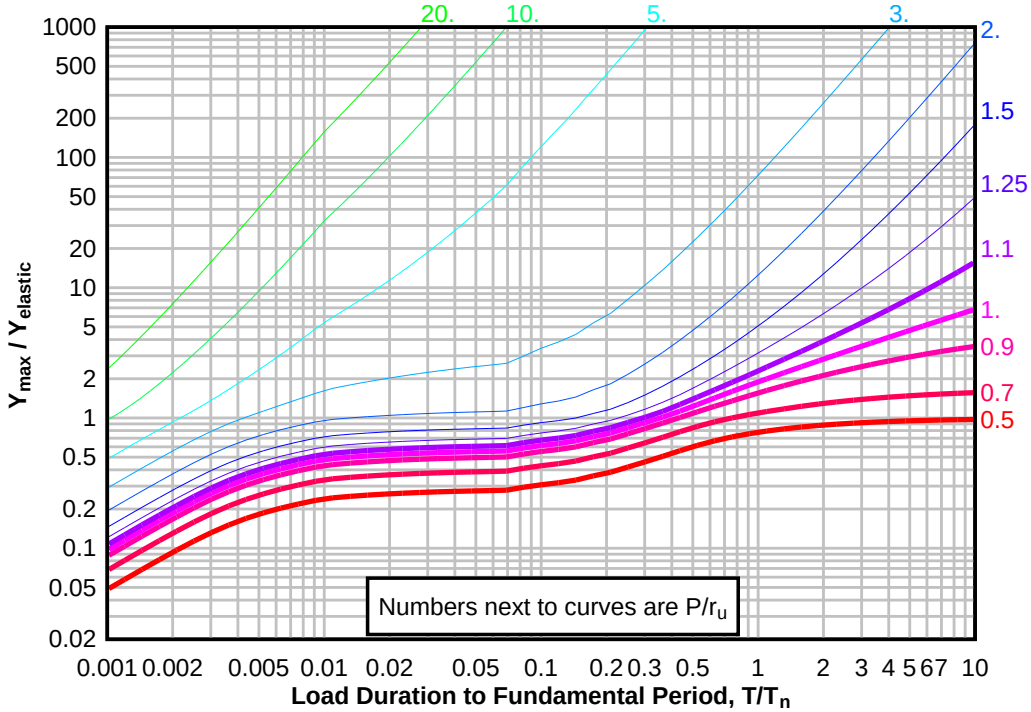


Figure 3-157(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.274, C2 = 100)

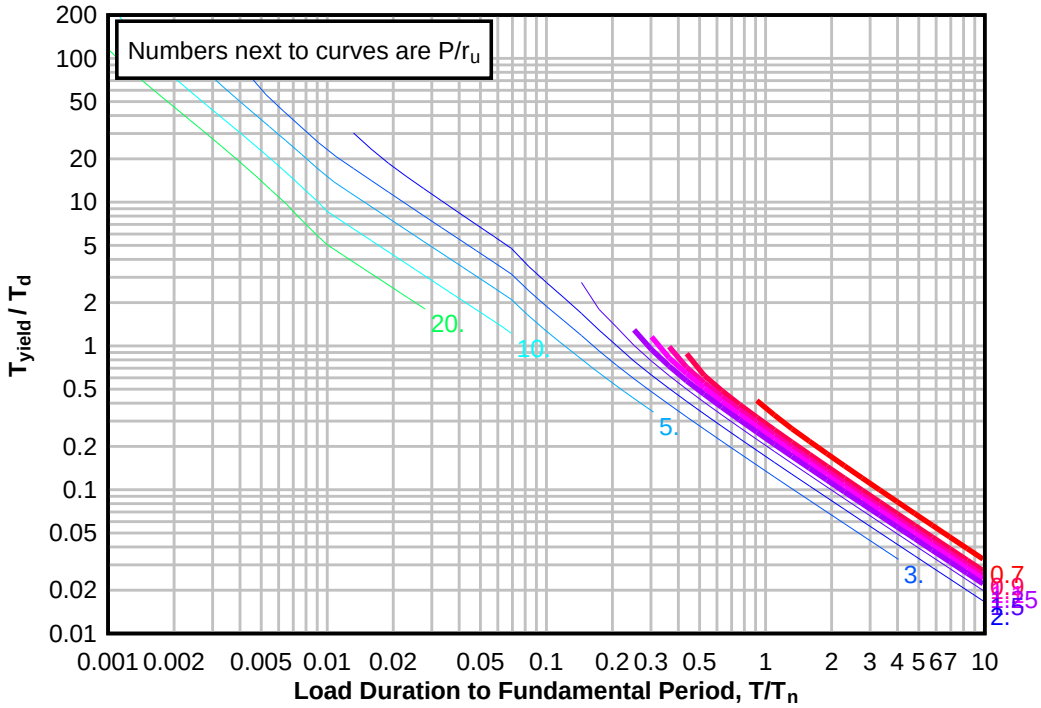


Figure 3-158(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.261, C_2 = 100)

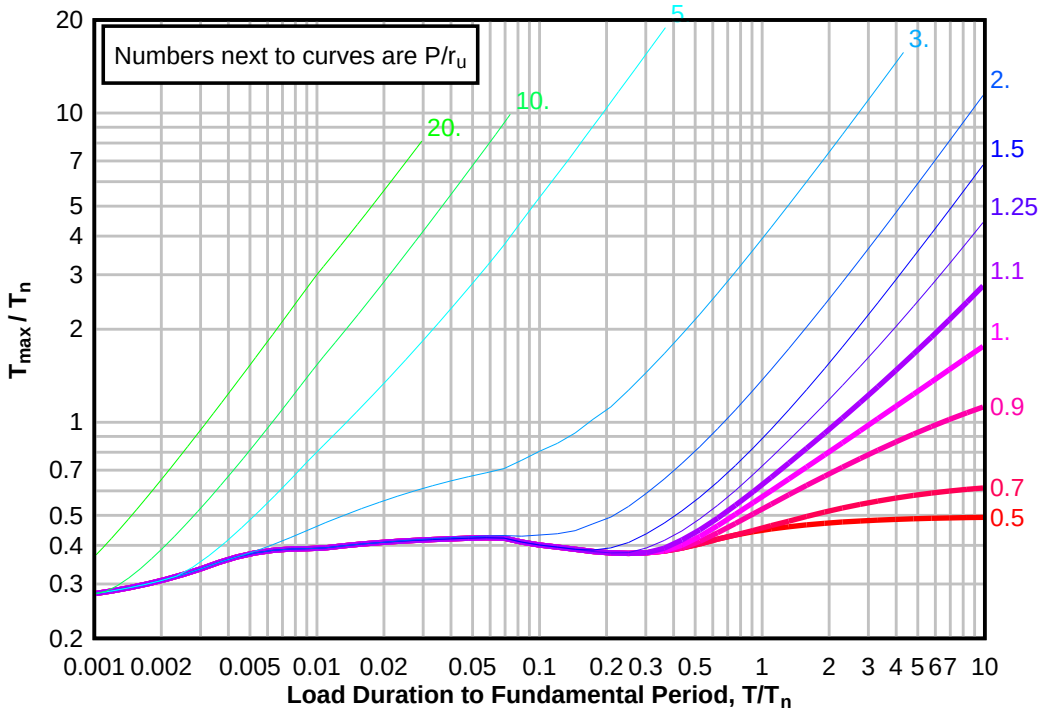


Figure 3-158(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.261, C2 = 100)

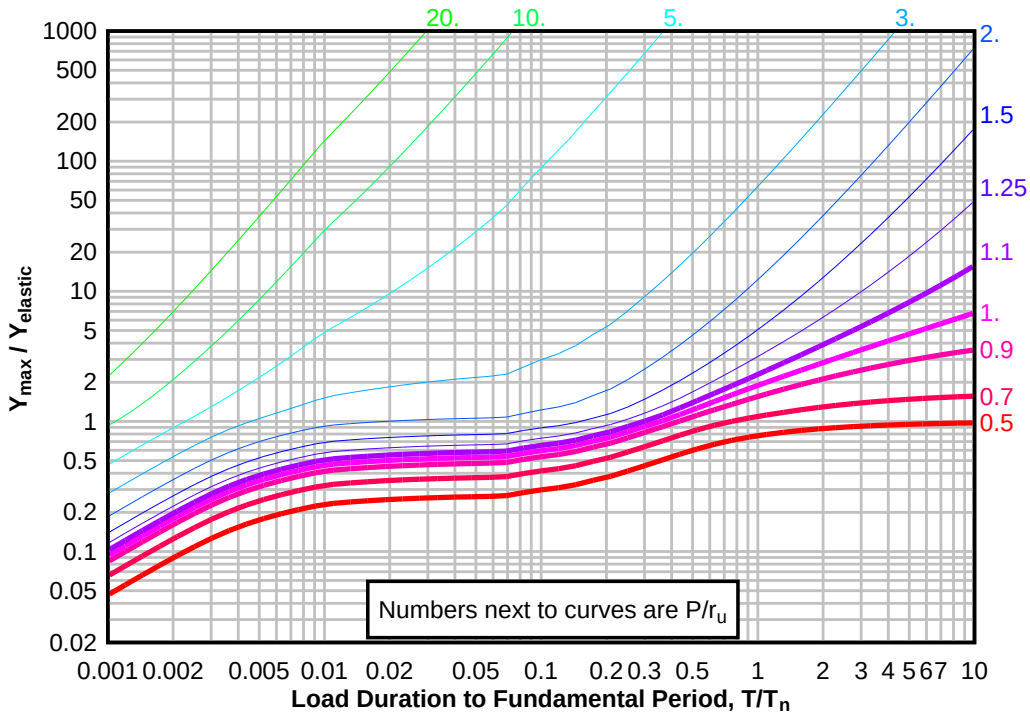


Figure 3-158(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.261, C2 = 100)

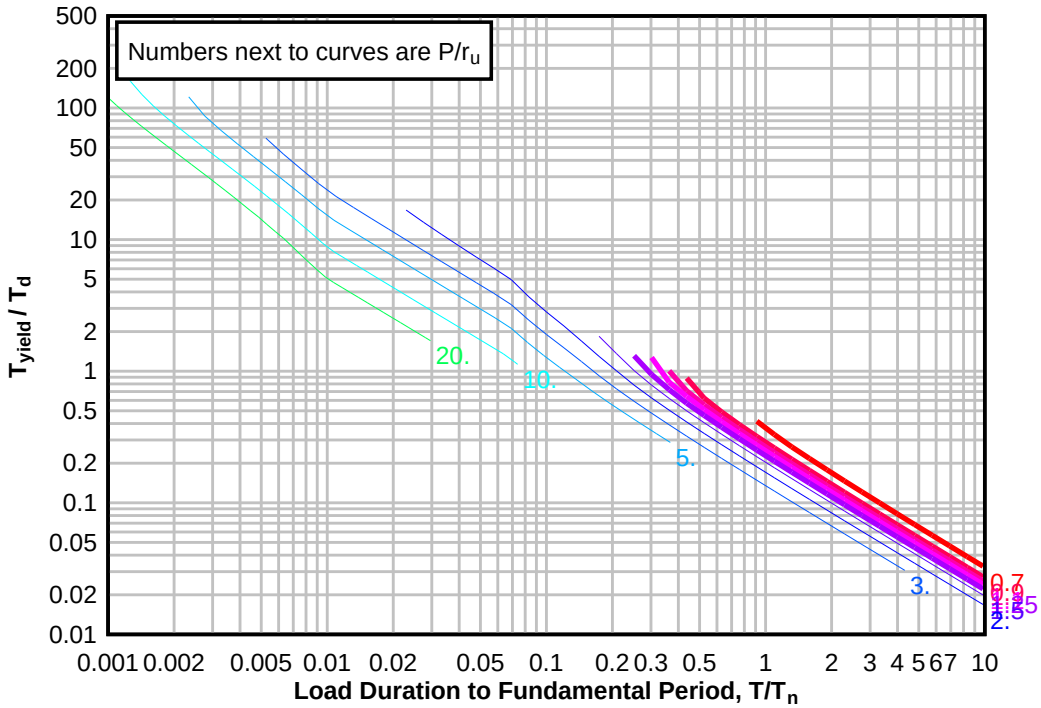


Figure 3-159(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.237, C_2 = 100)

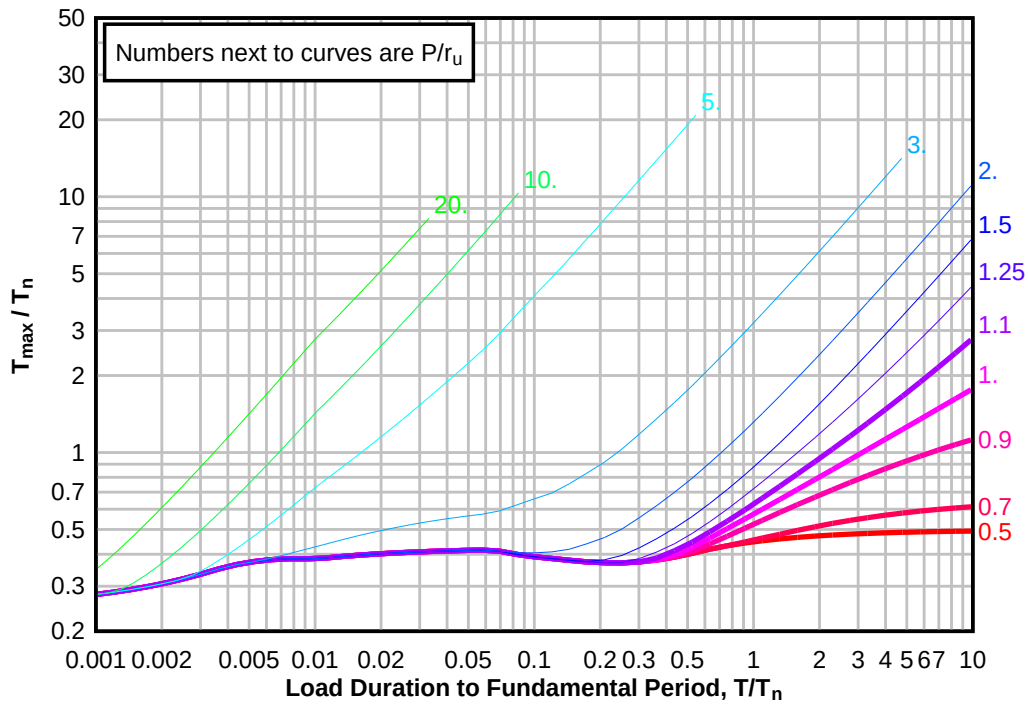


Figure 3-159(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.237, C2 = 100)

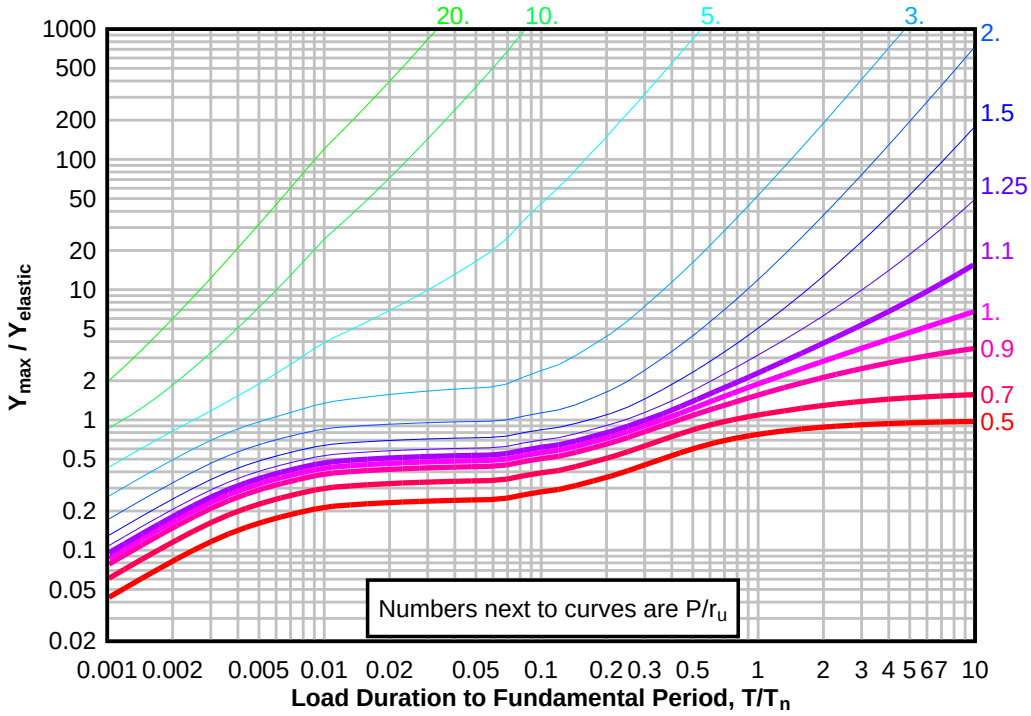


Figure 3-159(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.237, C2 = 100)

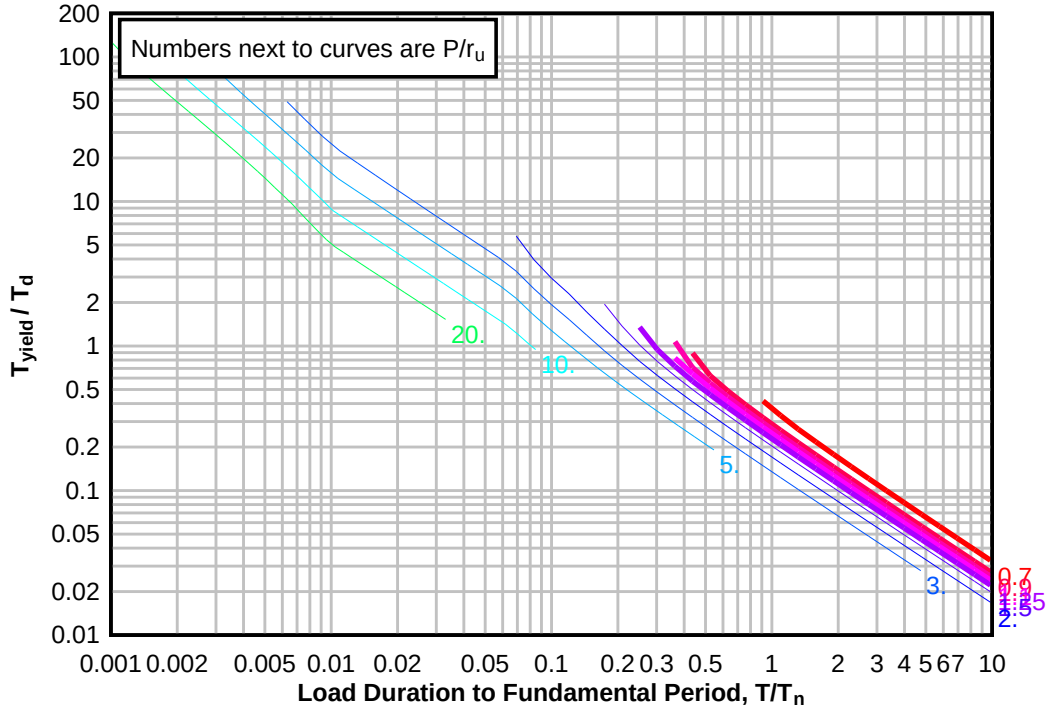


Figure 3-160(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.215, C_2 = 100)

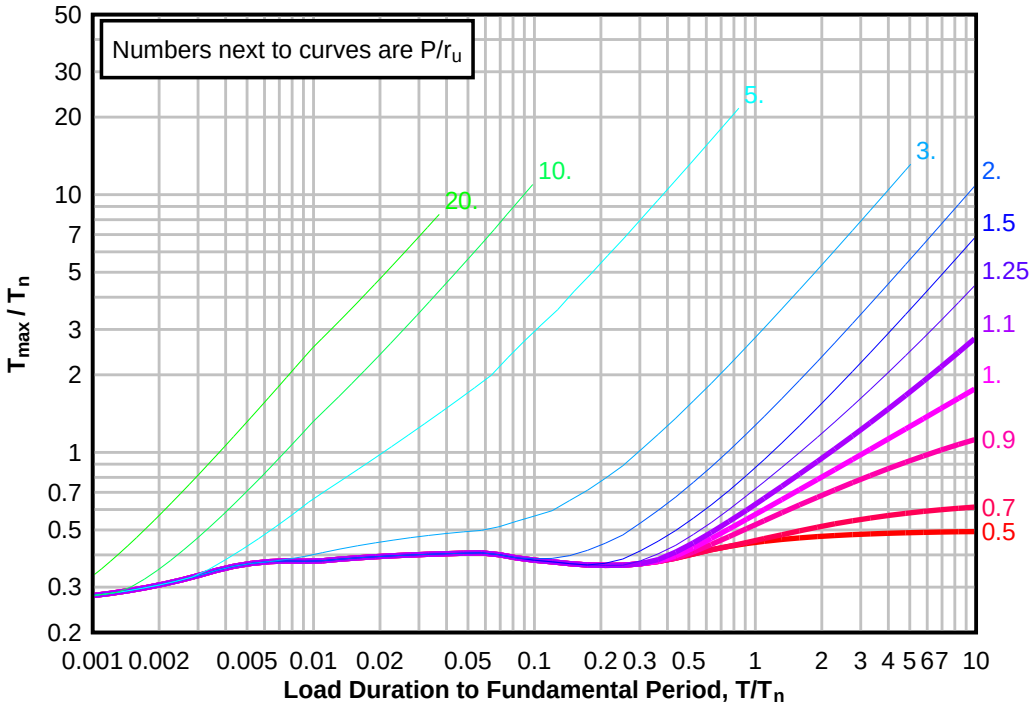


Figure 3-160(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.215, C2 = 100)

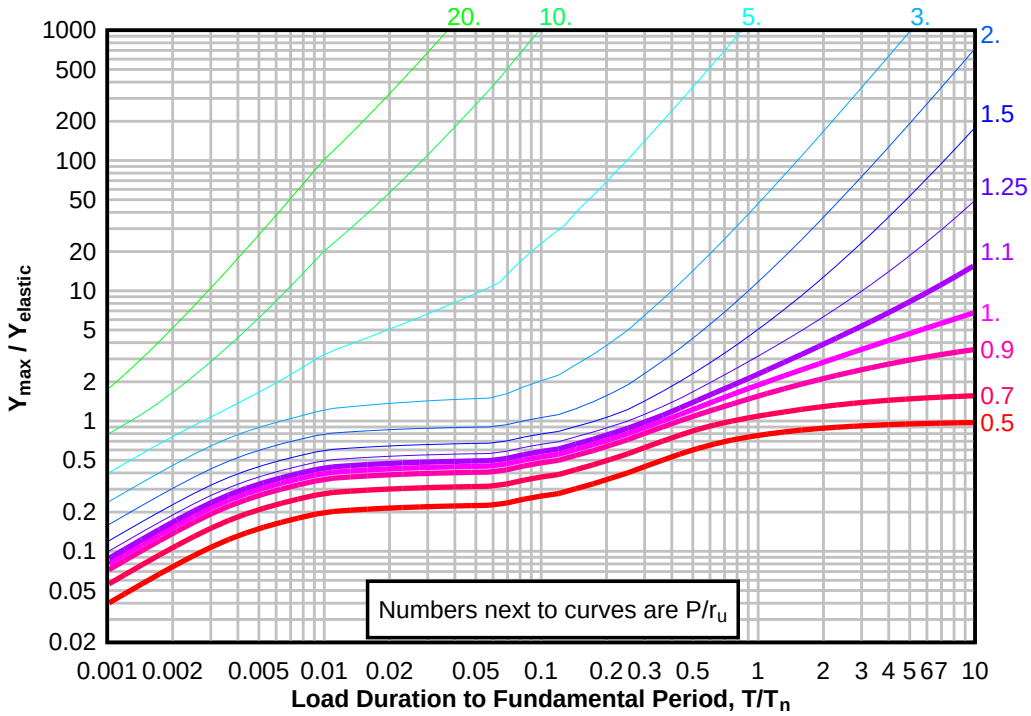


Figure 3-160(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.215, C2 = 100)

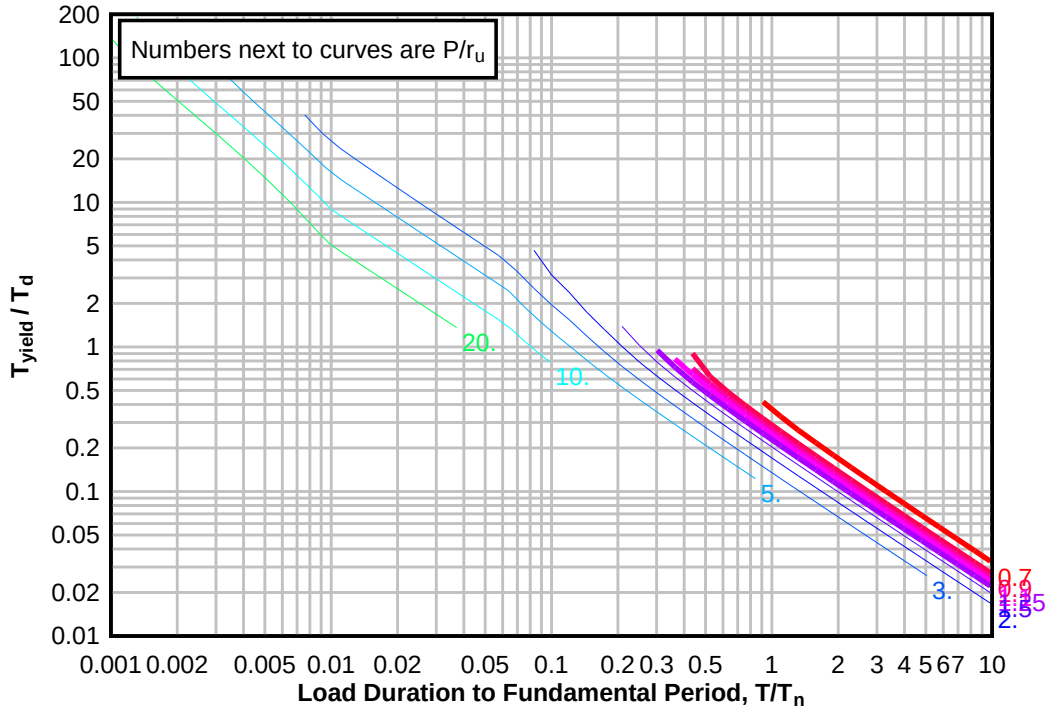


Figure 3-161(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.178, C_2 = 100)

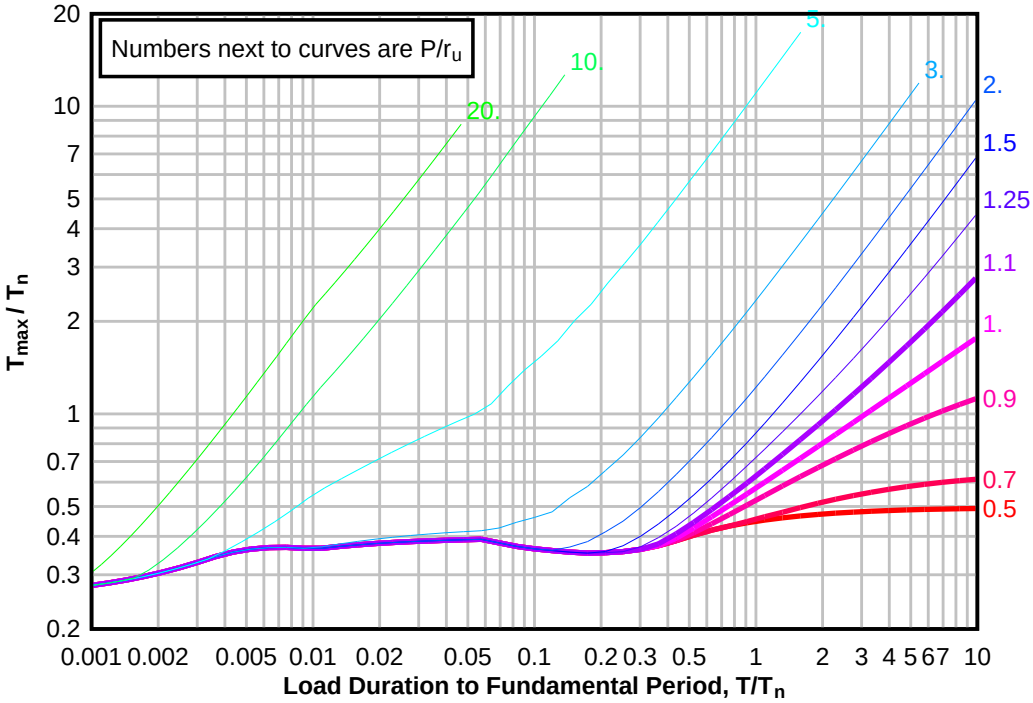


Figure 3-161(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.178, C2 = 100)

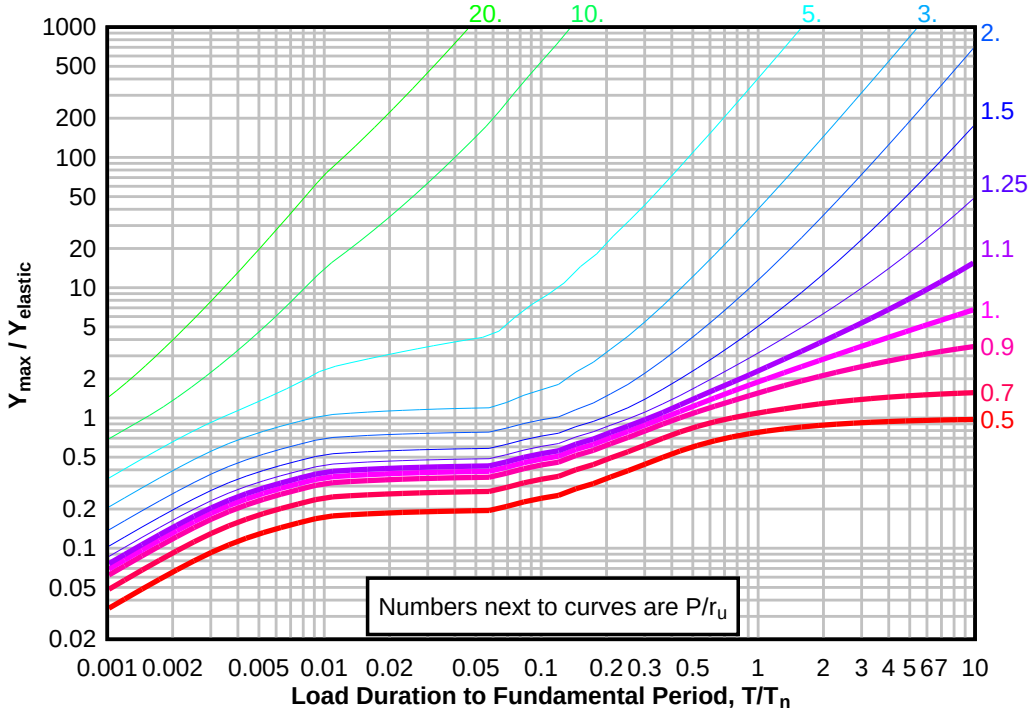


Figure 3-161(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.178, C2 = 100)

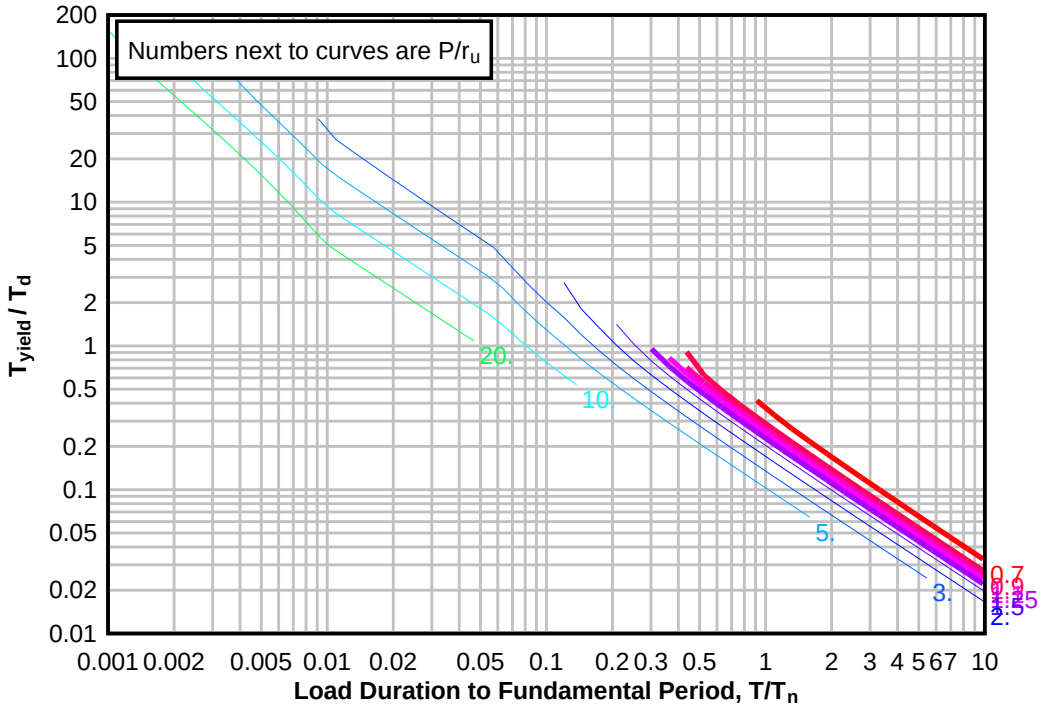


Figure 3-162(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.147, C_2 = 100)

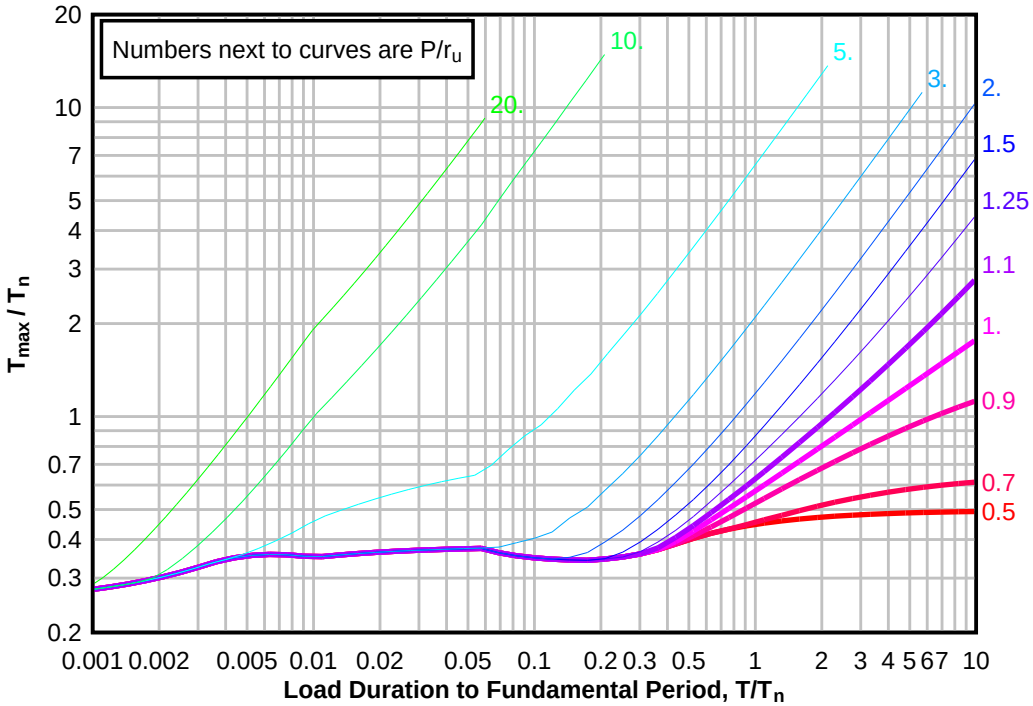


Figure 3-162(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.147, C2 = 100)

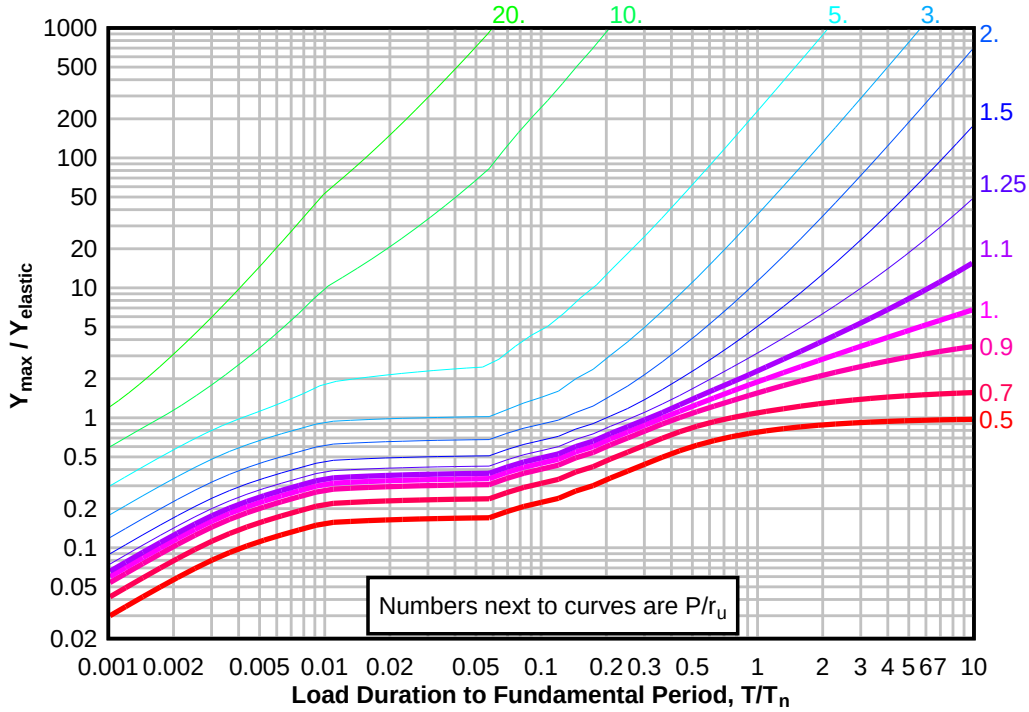


Figure 3-162(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.147, C2 = 100)

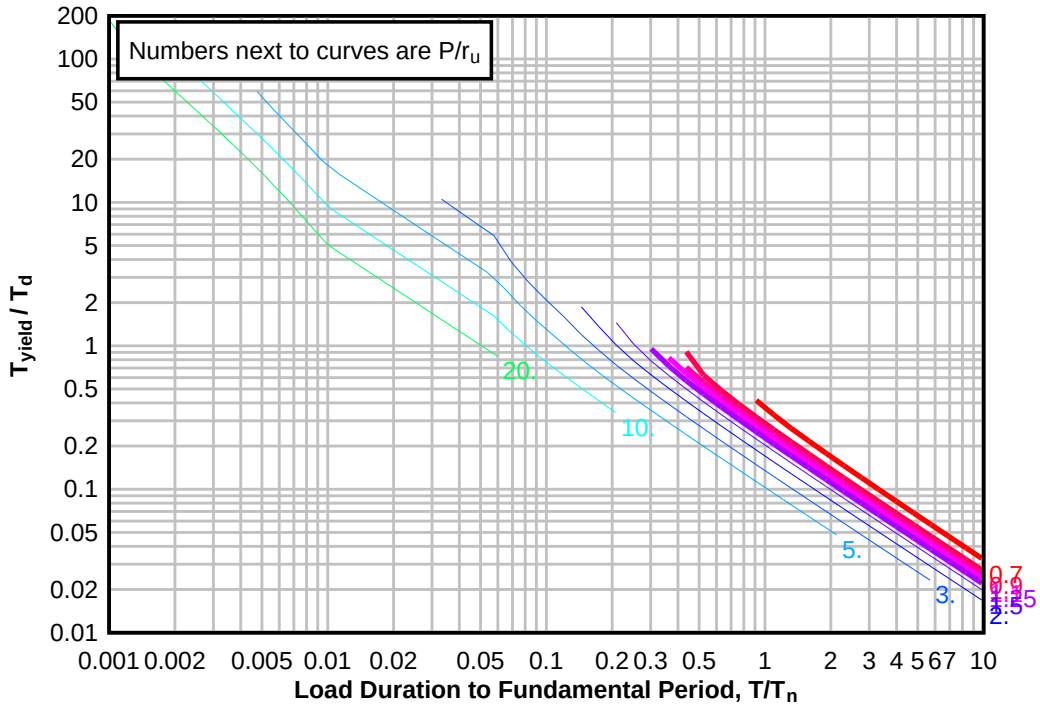


Figure 3-163(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.121, C_2 = 100)

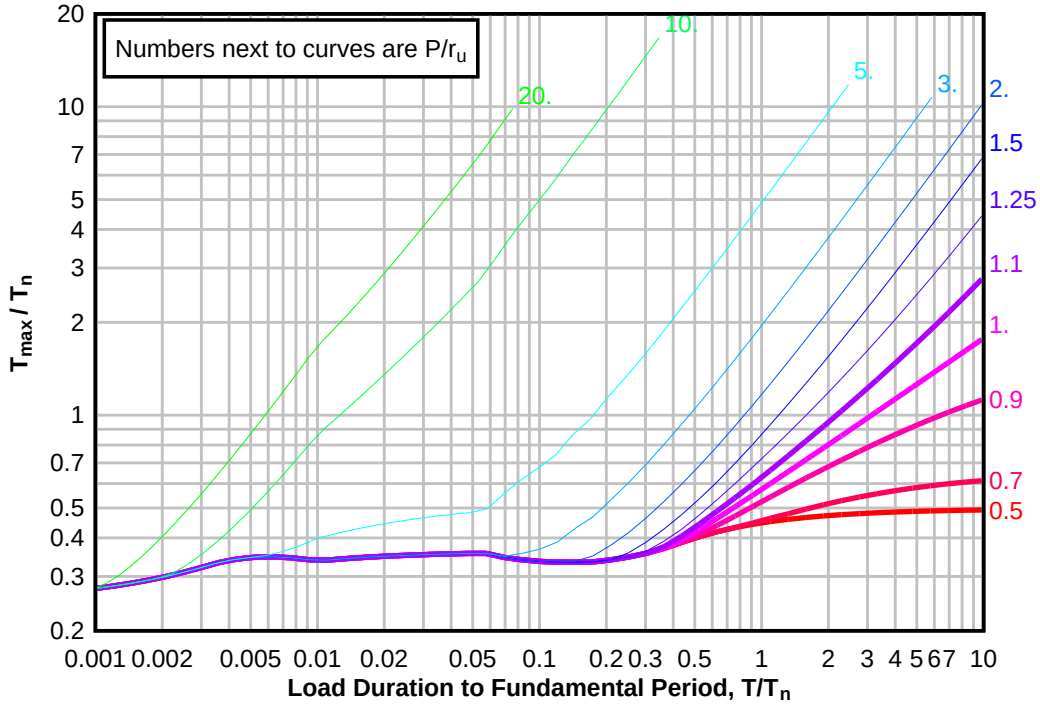


Figure 3-163(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.121, C2 = 100)

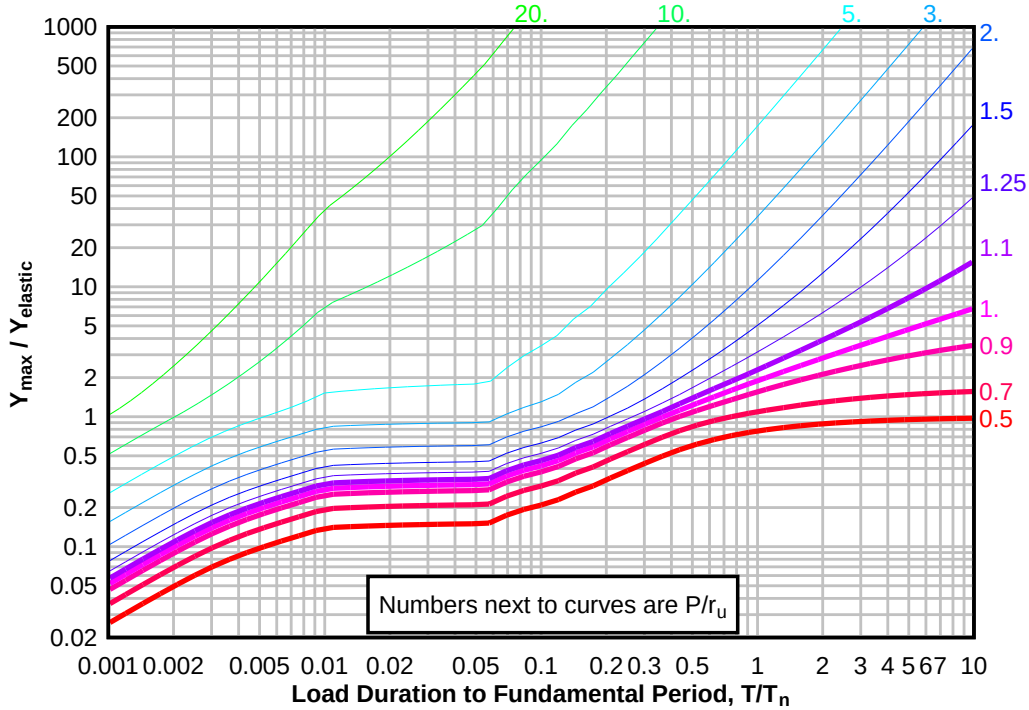


Figure 3-163(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.121, C2 = 100)

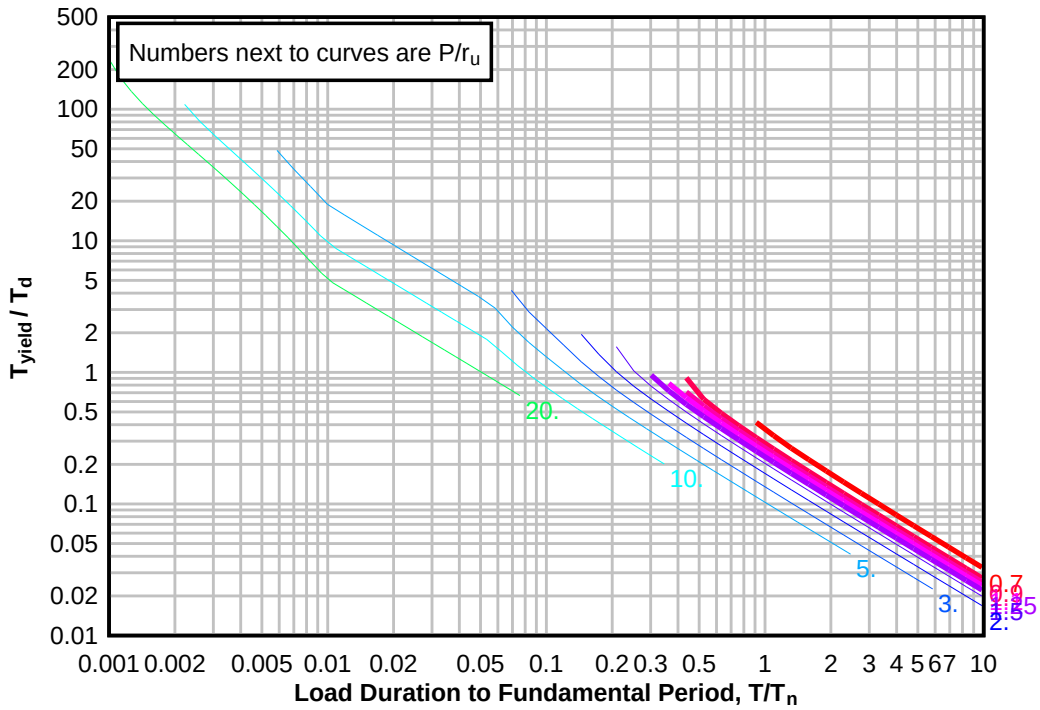


Figure 3-164(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.100, C_2 = 100)

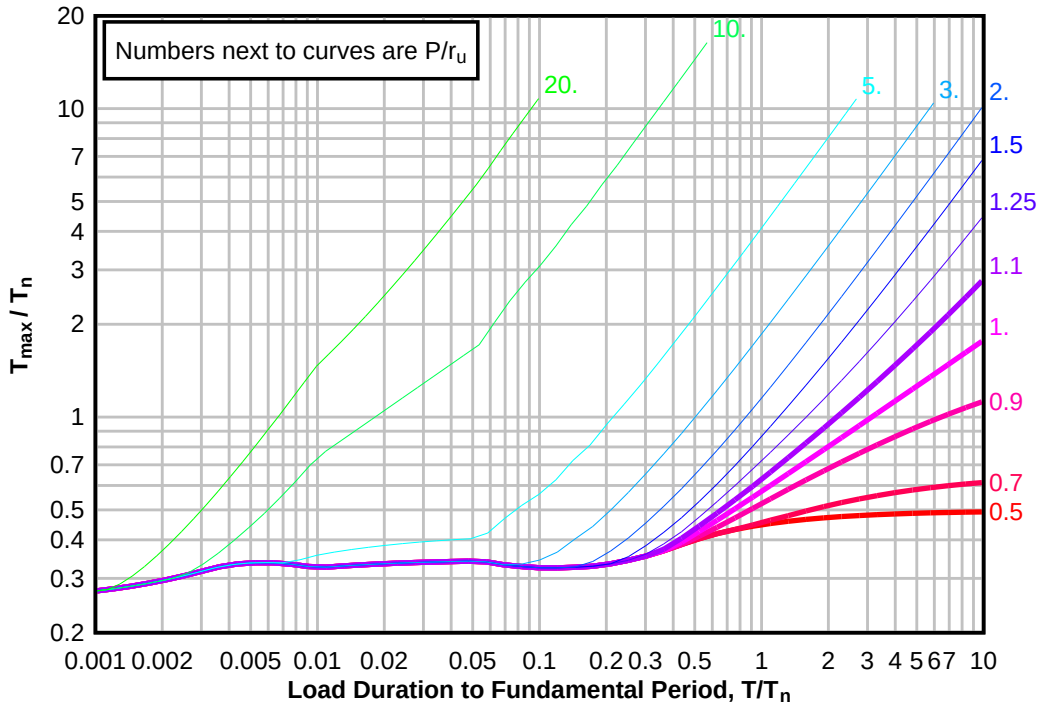


Figure 3-164(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.100, C2 = 100)

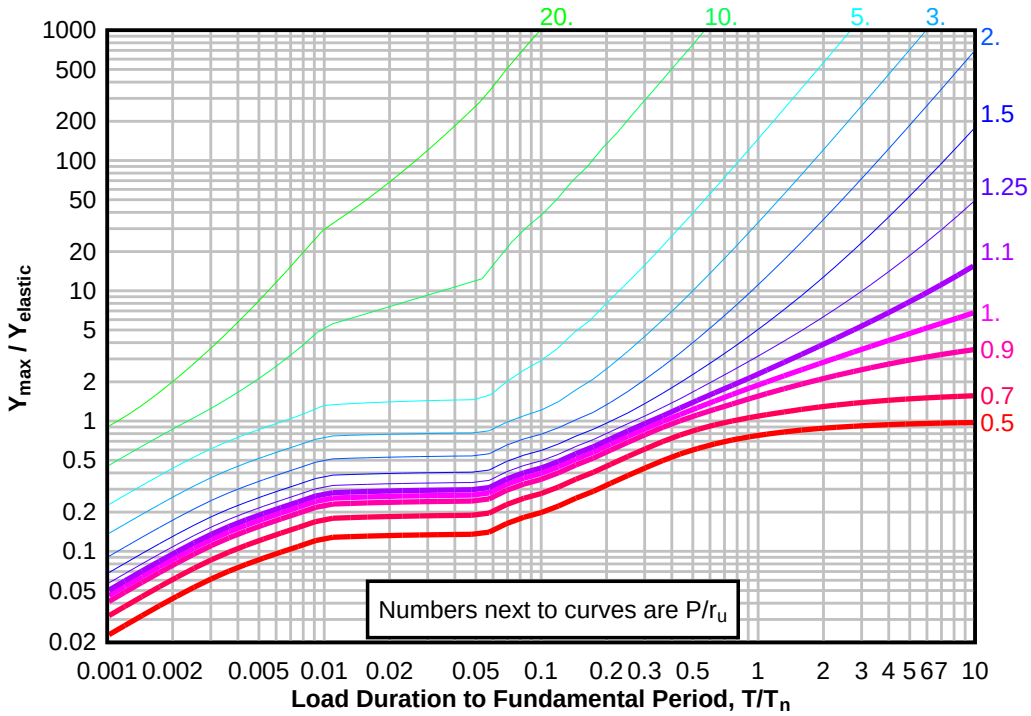


Figure 3-164(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.100, C2 = 100)

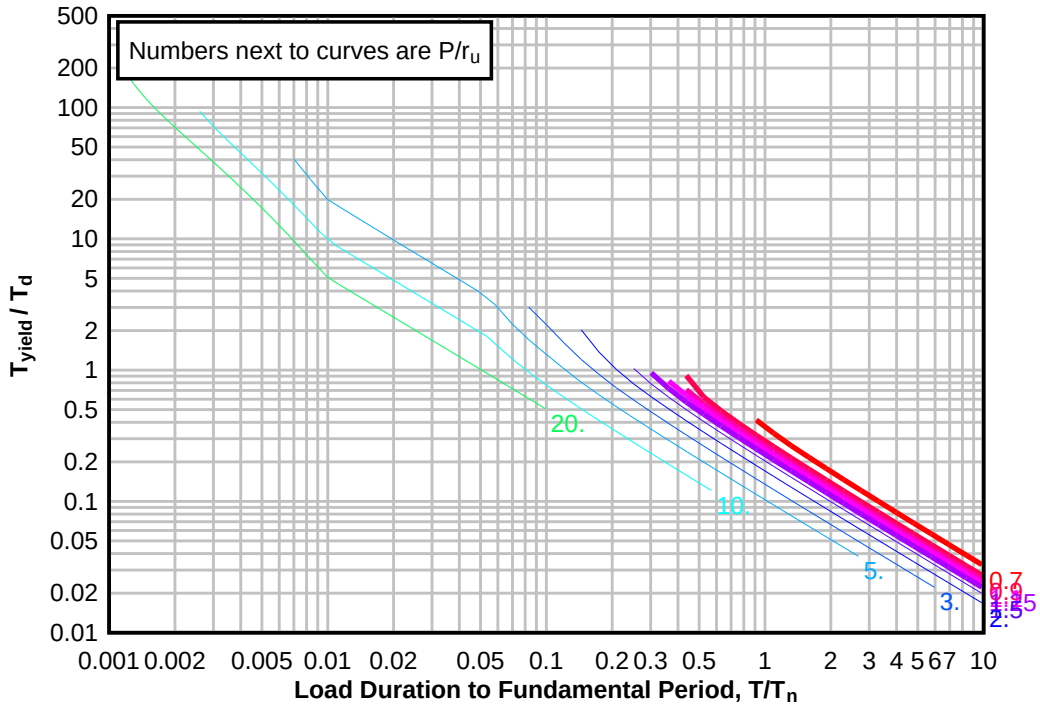


Figure 3-165(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.075, C_2 = 100)

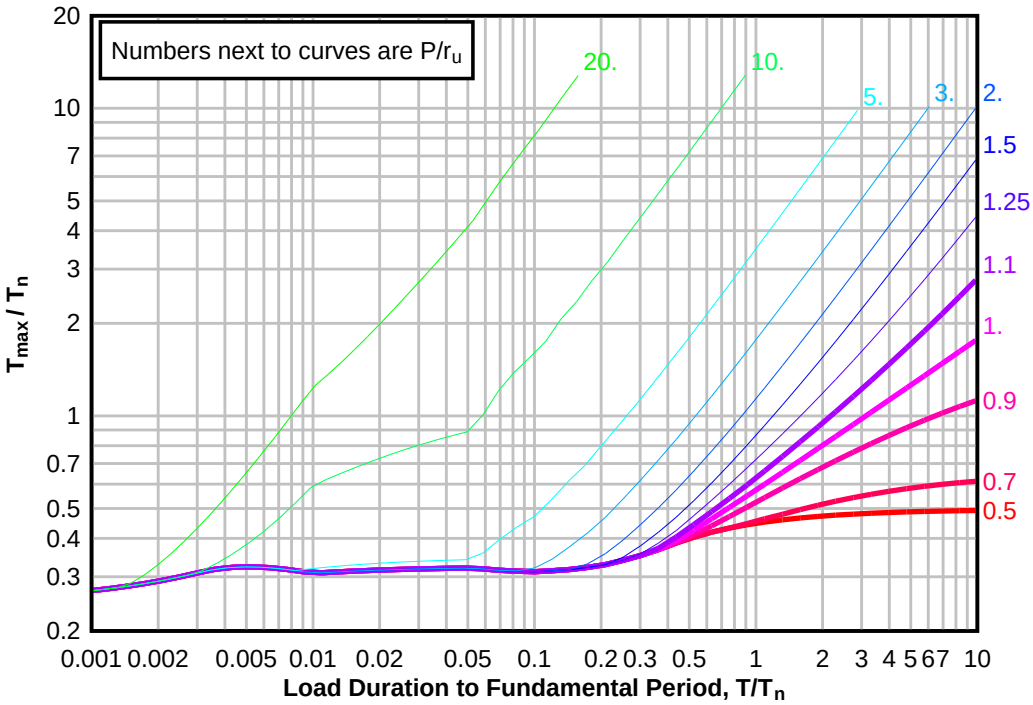


Figure 3-165(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.075, C2 = 100)

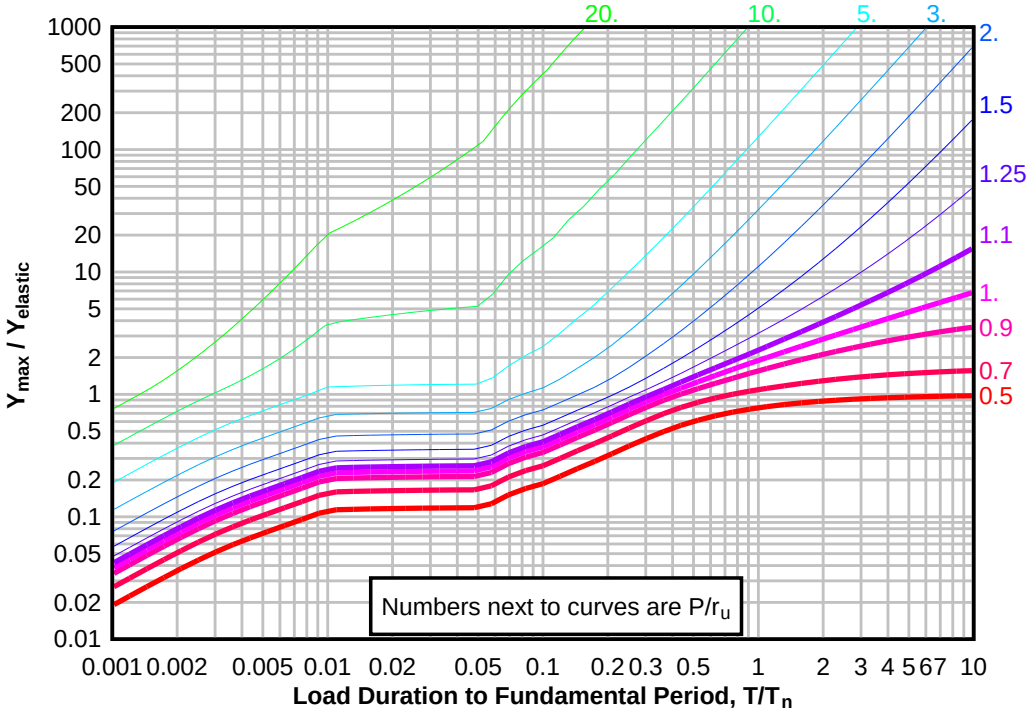


Figure 3-165(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.075, C2 = 100)

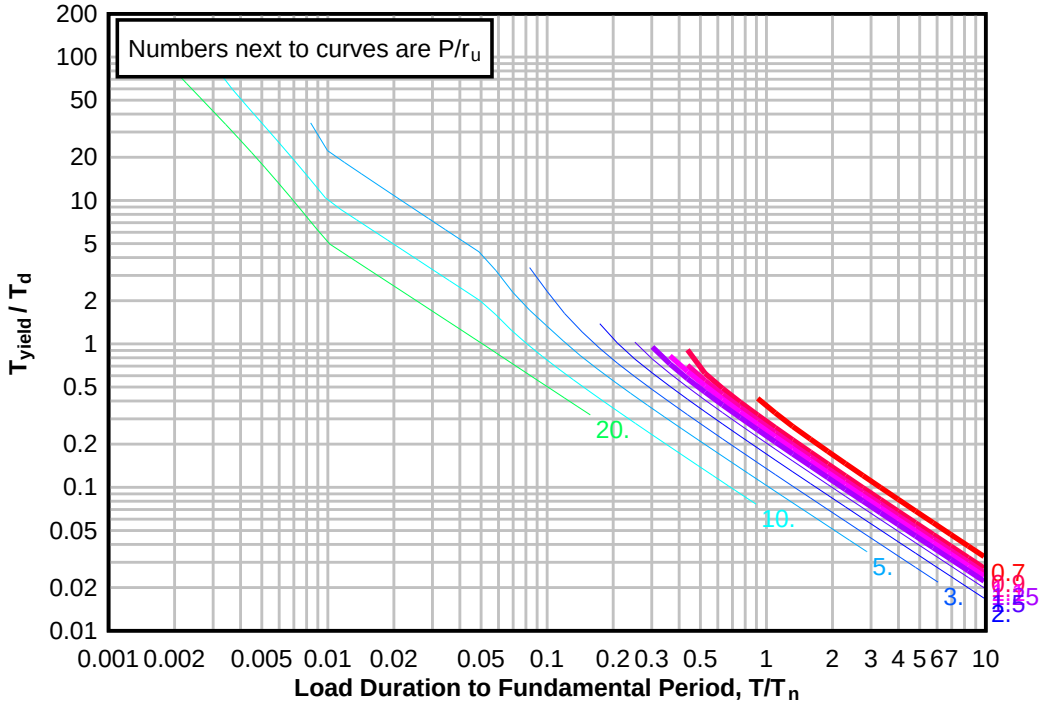


Figure 3-166(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.056, C_2 = 100)

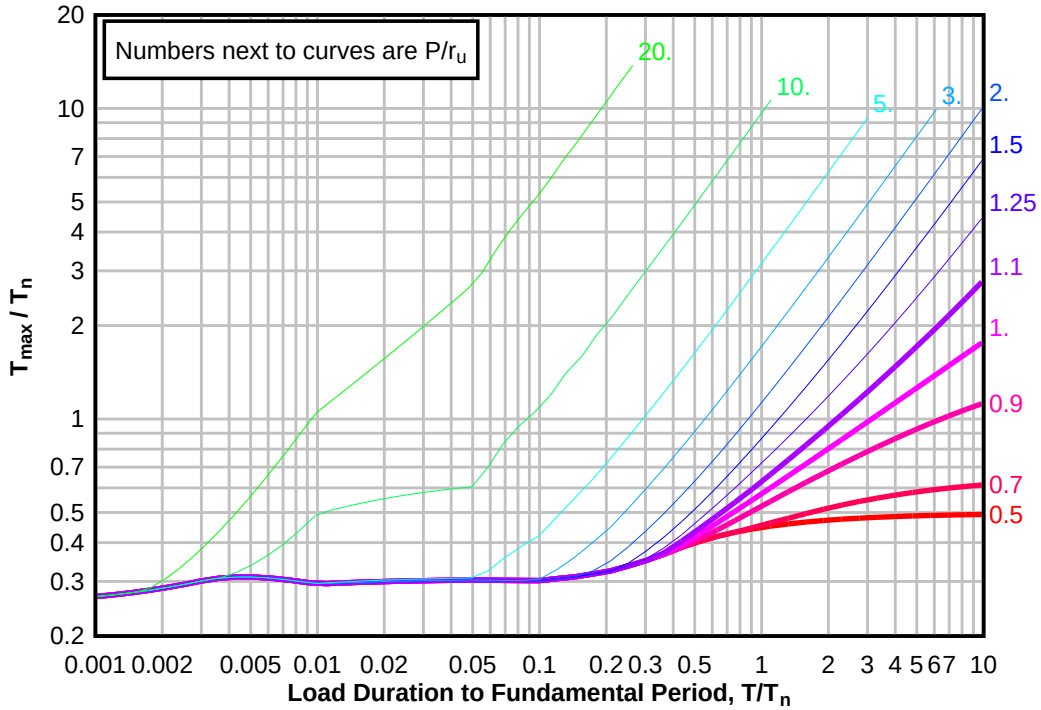


Figure 3-166(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.056, C2 = 100)

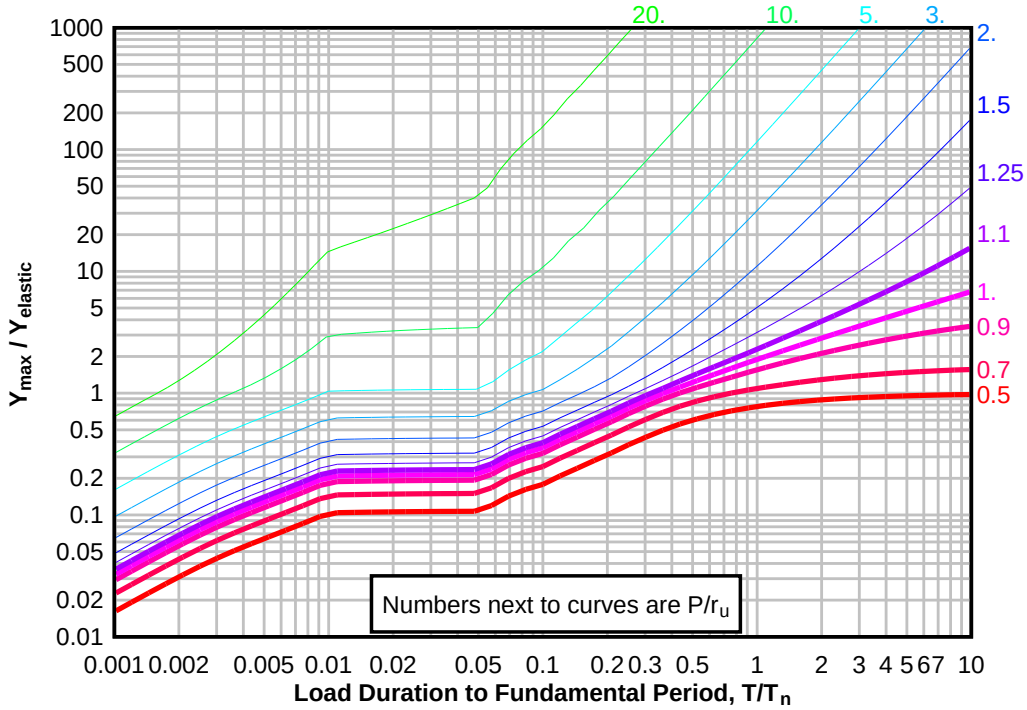


Figure 3-166(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.056, C2 = 100)

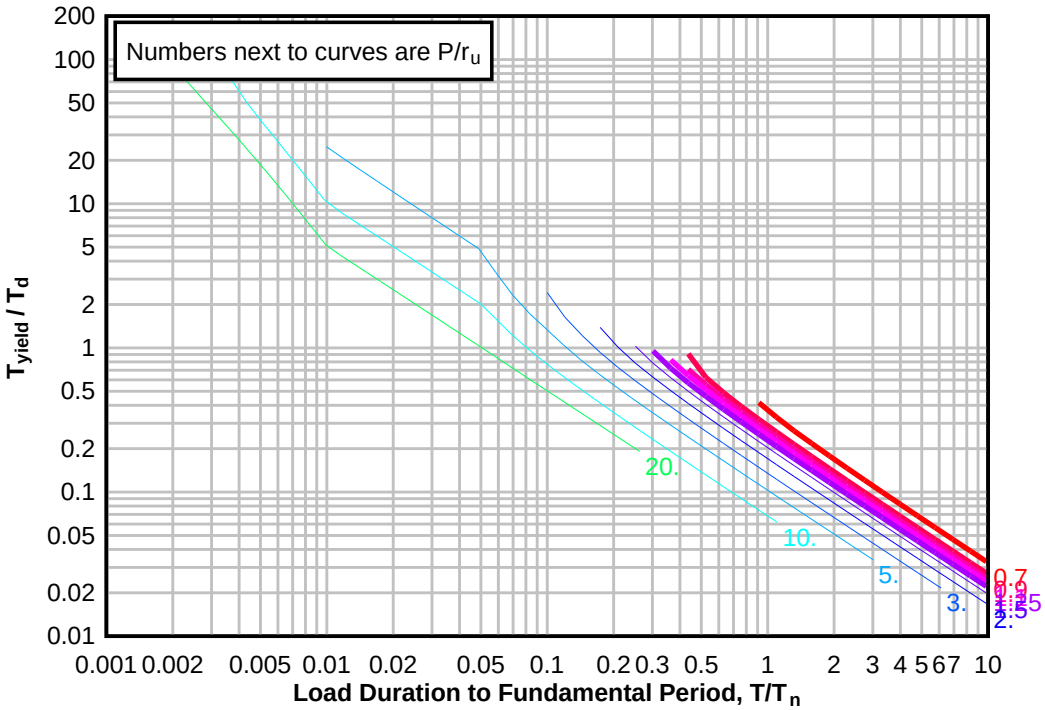


Figure 3-167(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.042, C_2 = 100)

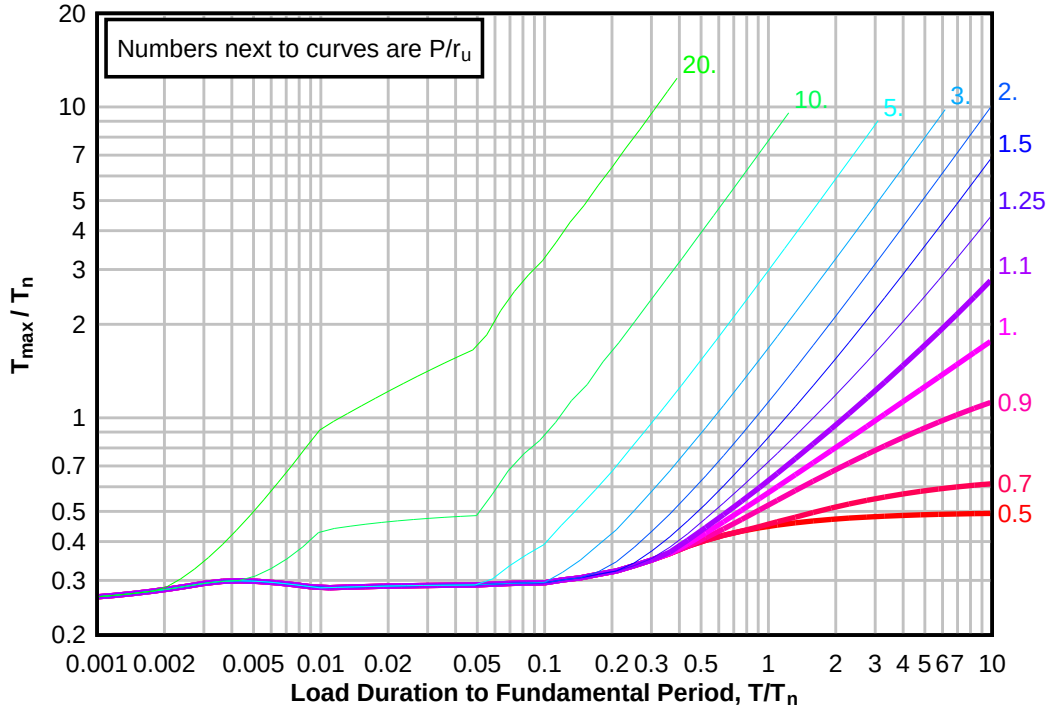


Figure 3-167(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.042, C2 = 100)

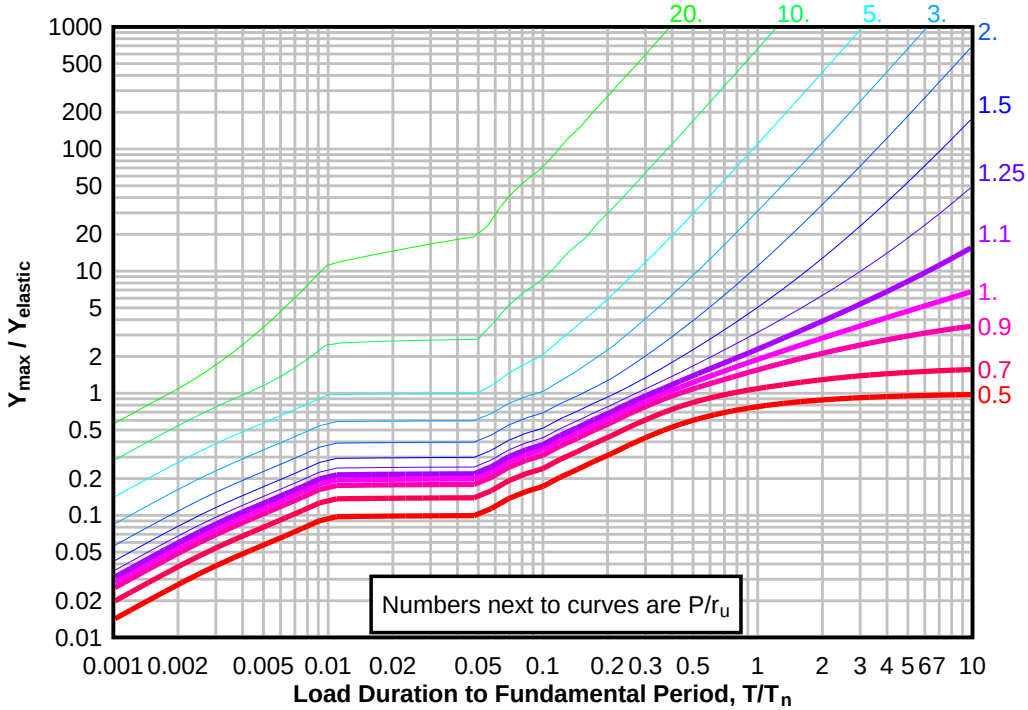


Figure 3-167(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.042, C2 = 100)

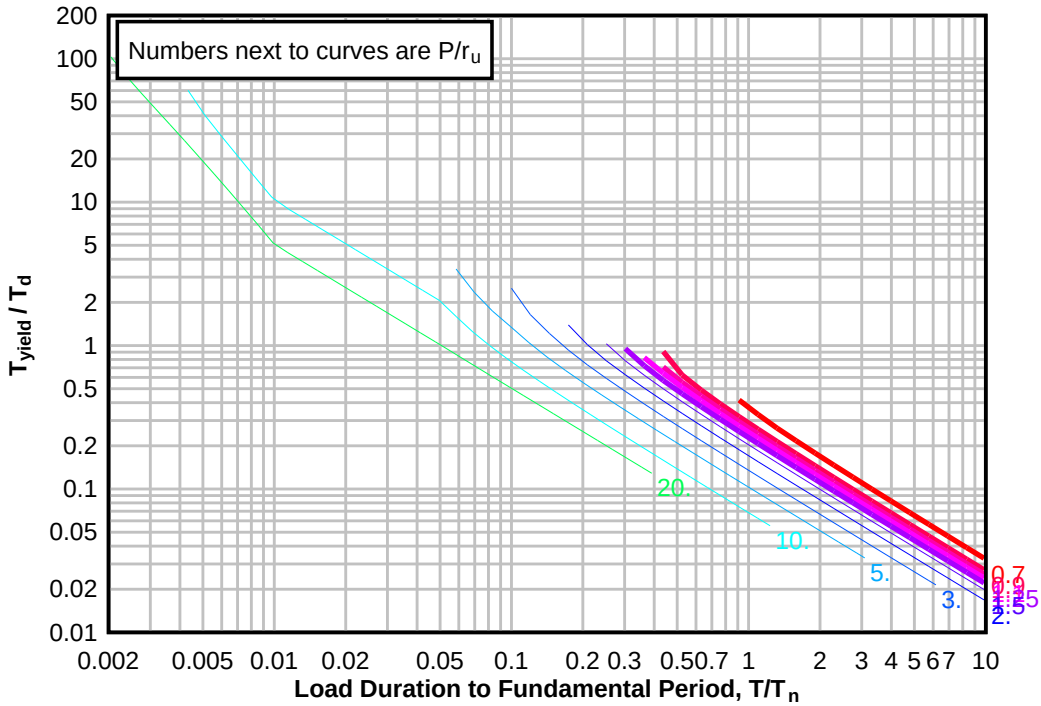


Figure 3-168(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.032, C_2 = 100)

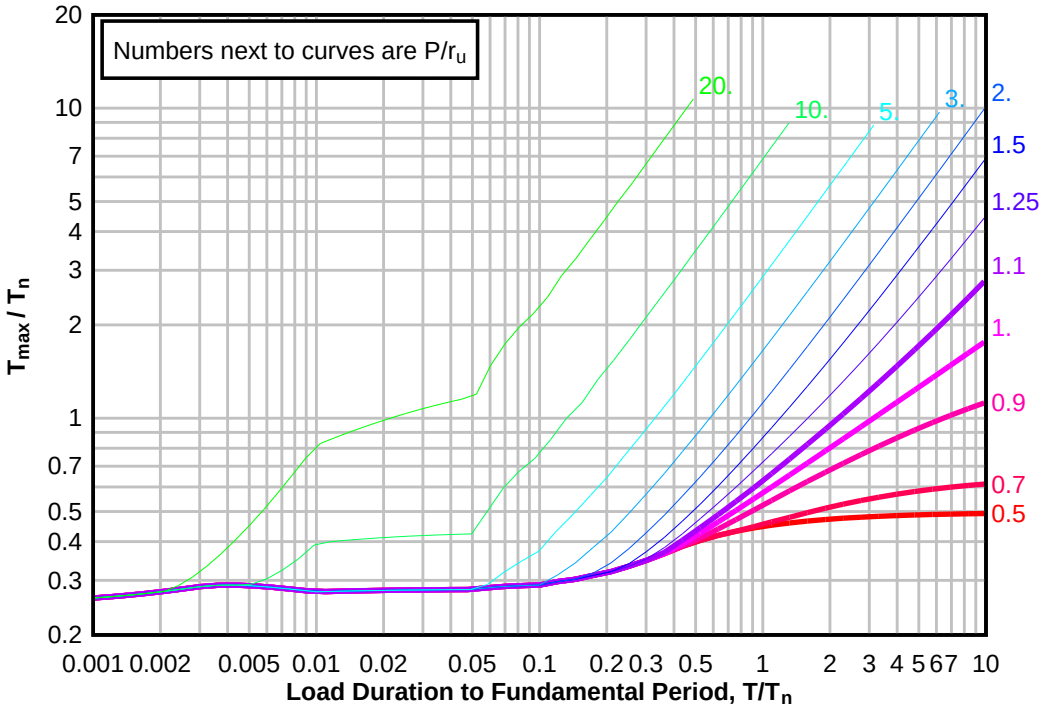


Figure 3-168(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.032, C2 = 100)

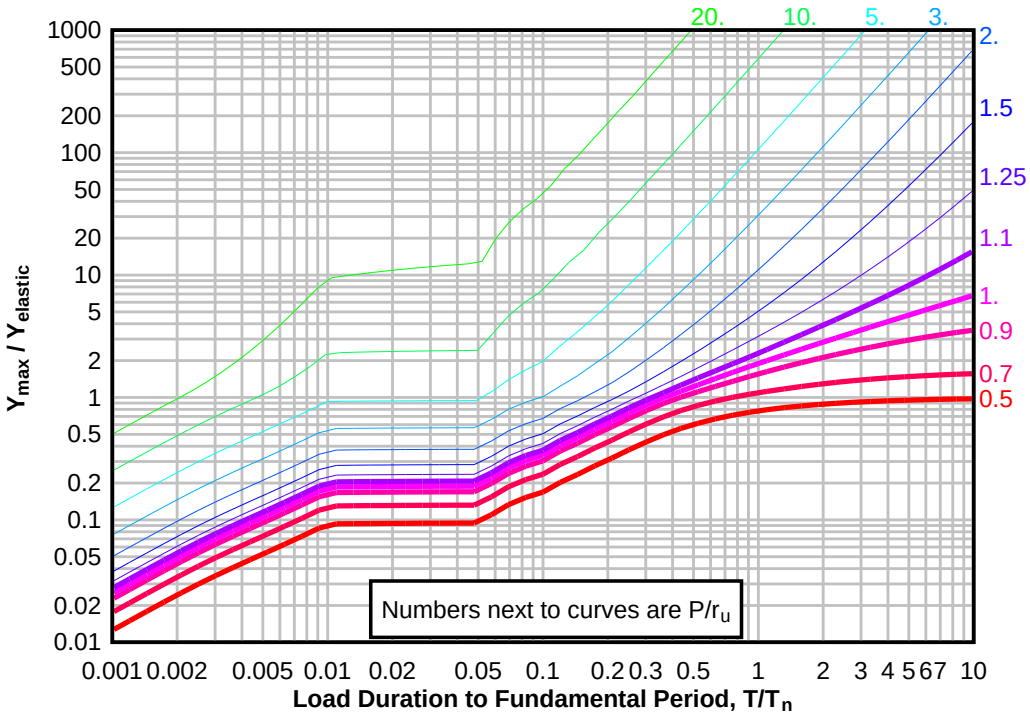


Figure 3-168(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.032, C2 = 100)

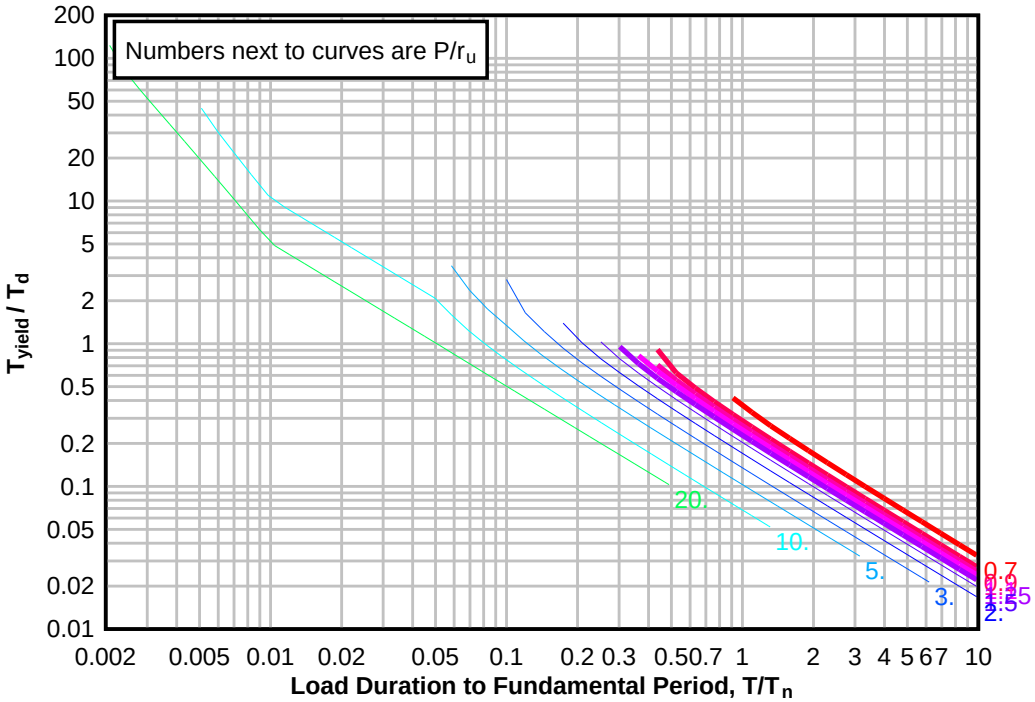


Figure 3-169(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.026, C_2 = 100)

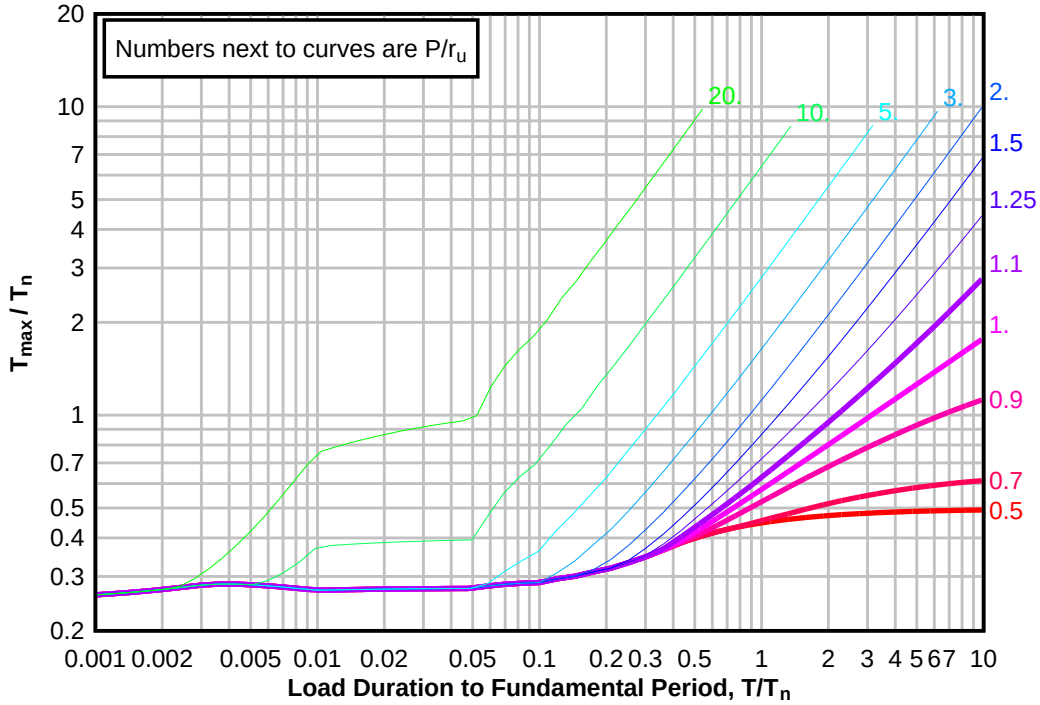


Figure 3-169(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.026, C2 = 100)

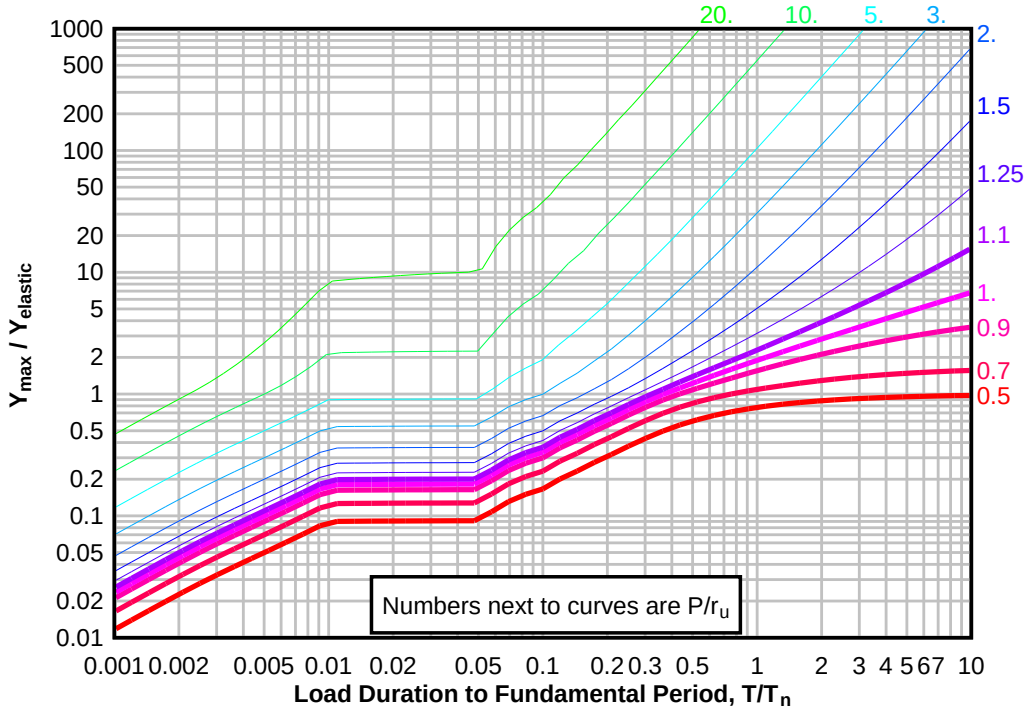


Figure 3-169(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.026, C2 = 100)

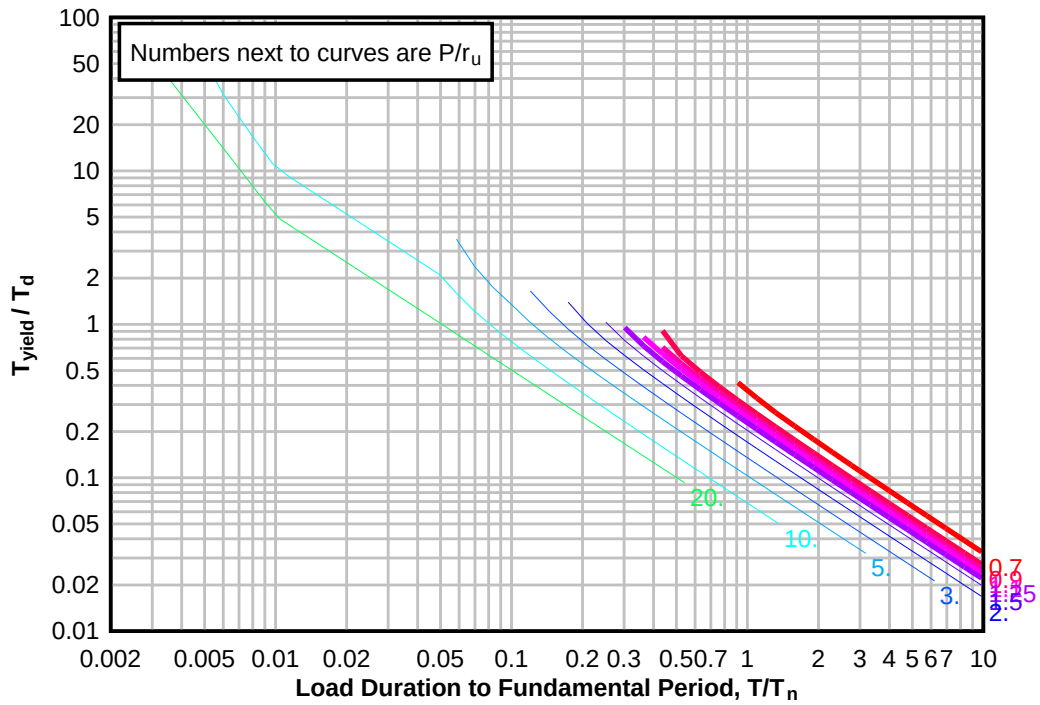


Figure 3-170(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.018, C_2 = 100)

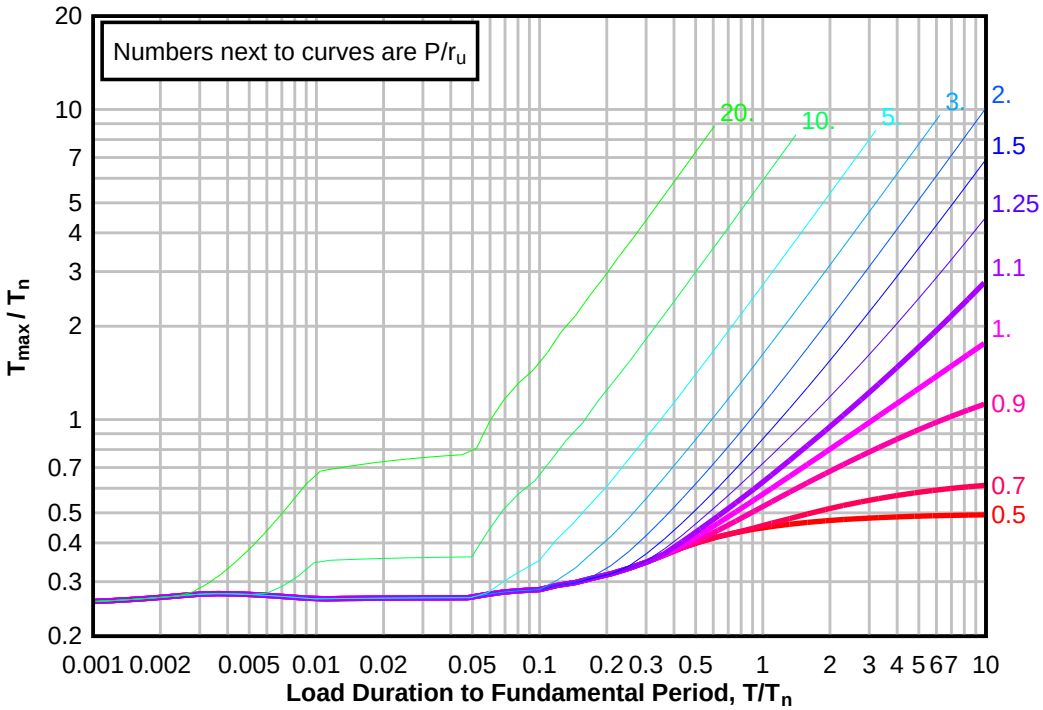


Figure 3-170(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.018, C2 = 100)

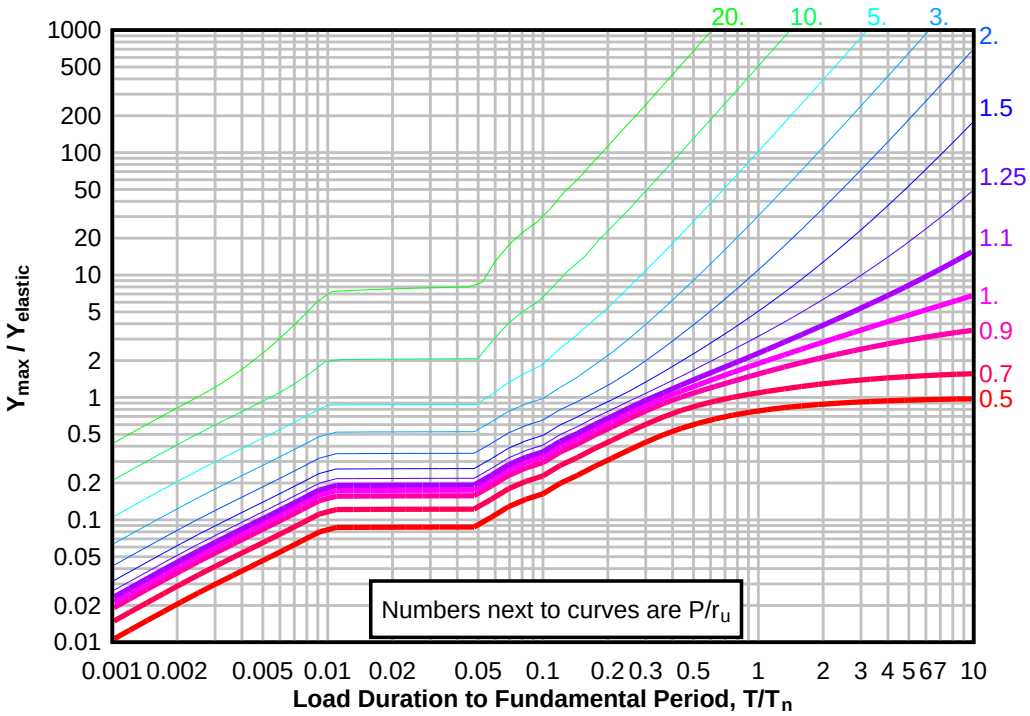


Figure 3-170(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.018, C2 = 100)

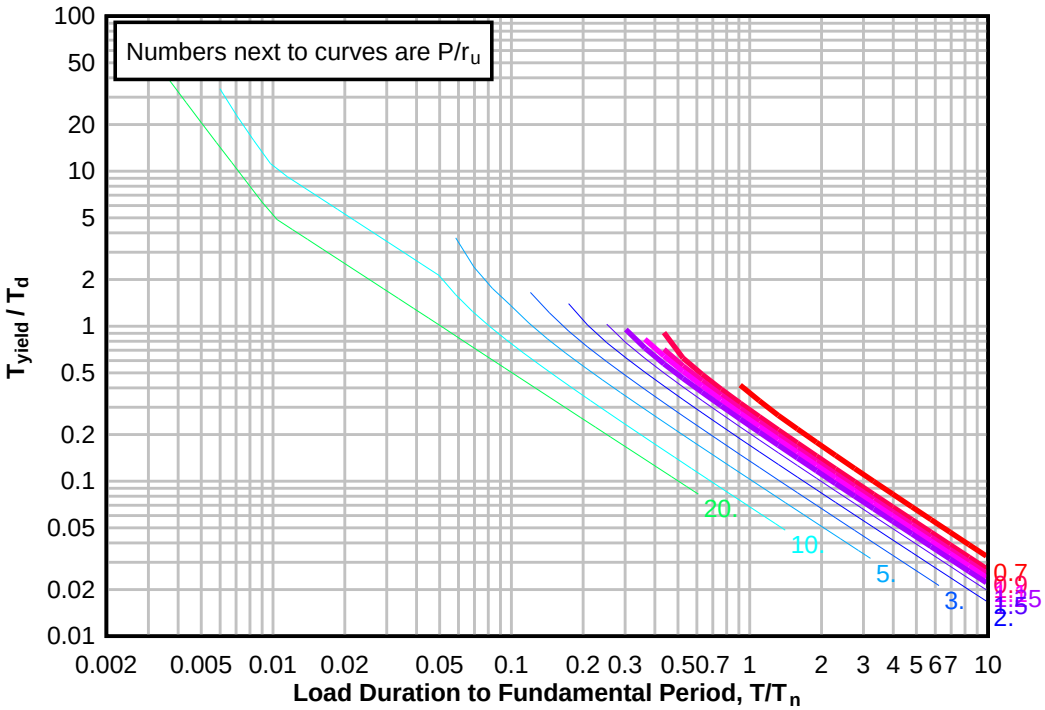


Figure 3-171(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.013, C_2 = 100)

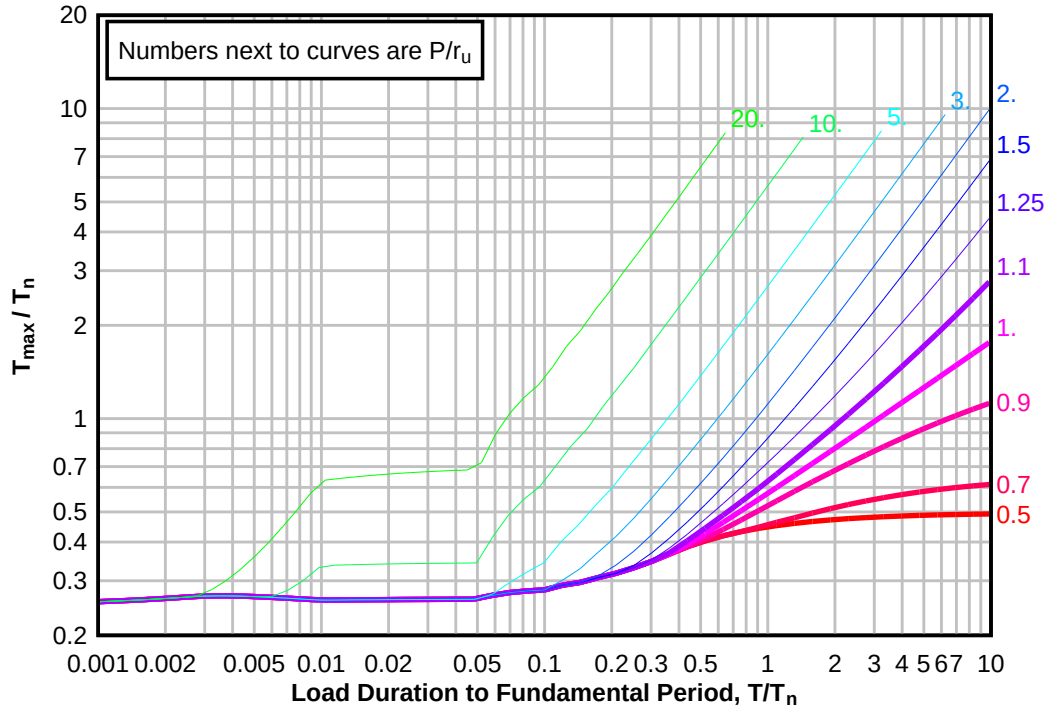


Figure 3-171(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.013, C2 = 100)

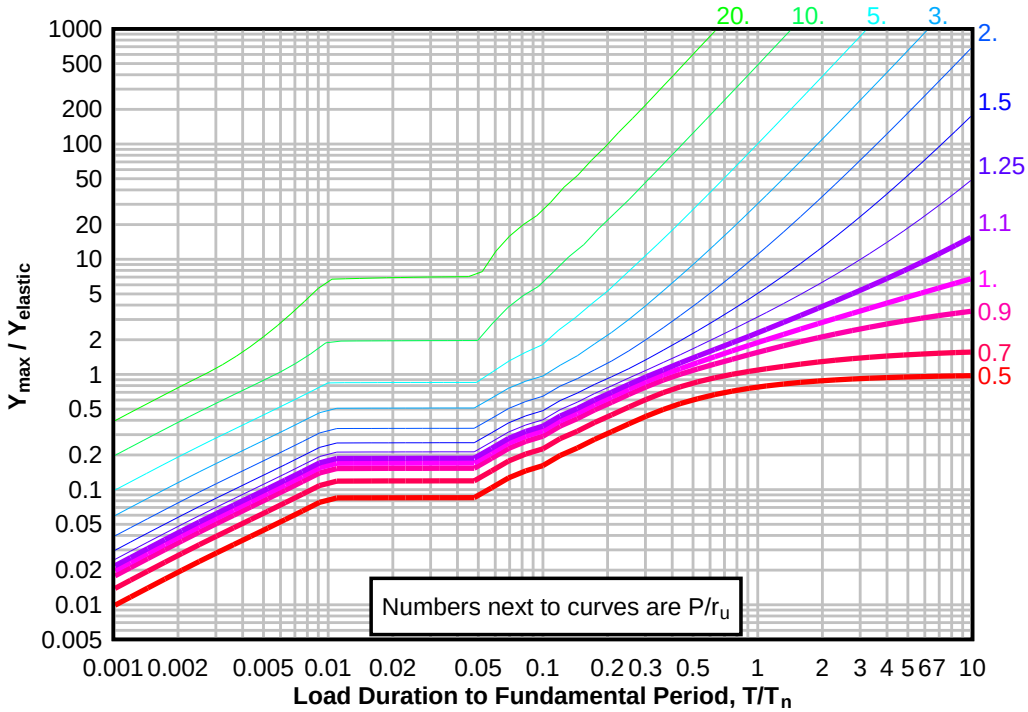


Figure 3-171(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.013, C2 = 100)

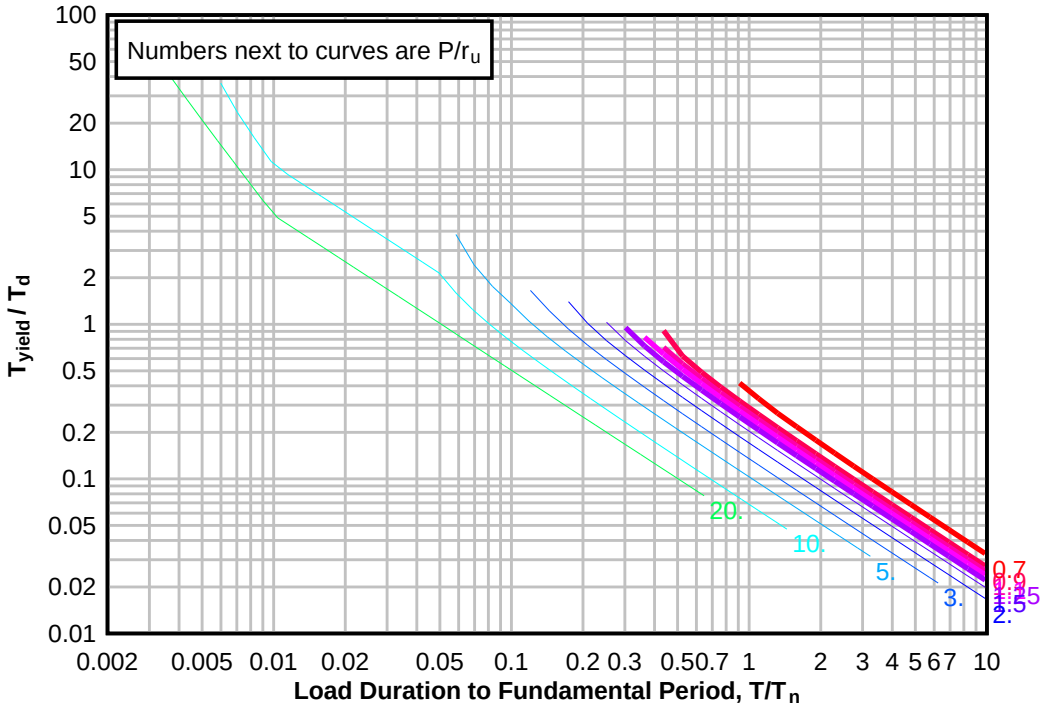


Figure 3-172(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.010, C_2 = 100)

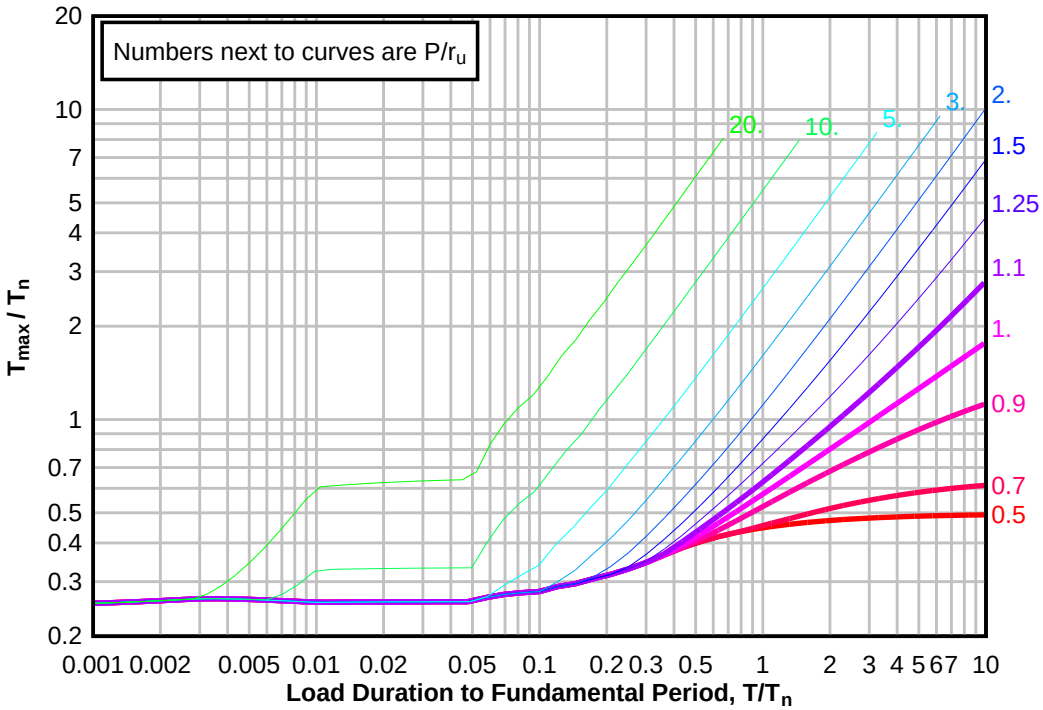


Figure 3-172(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.010, C2 = 100)

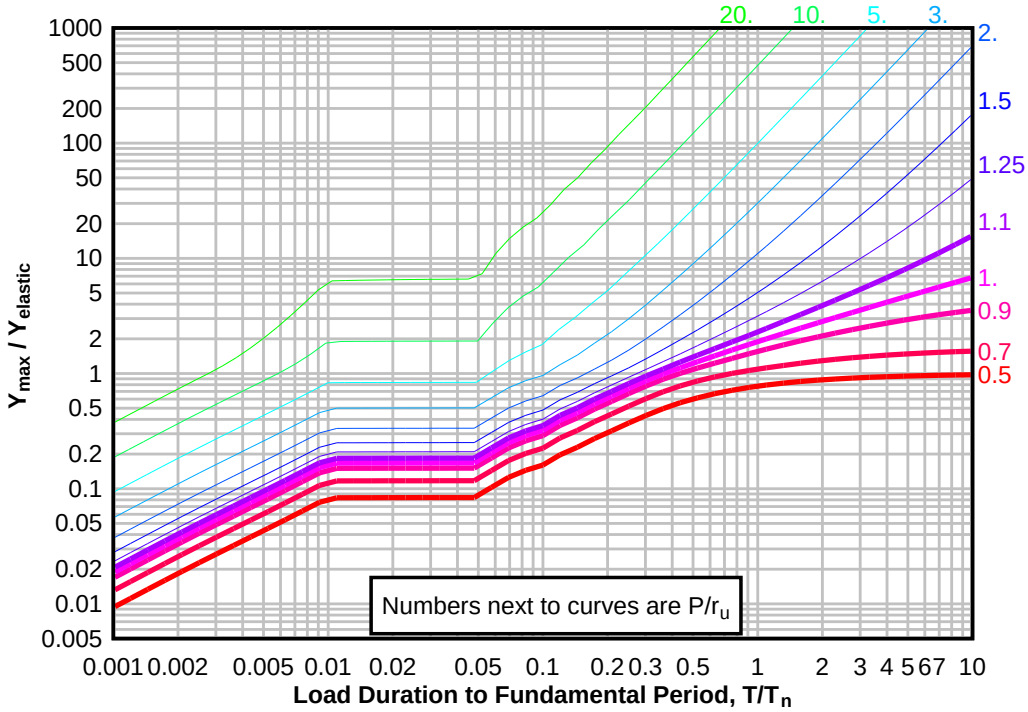


Figure 3-172(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.010, C2 = 100)

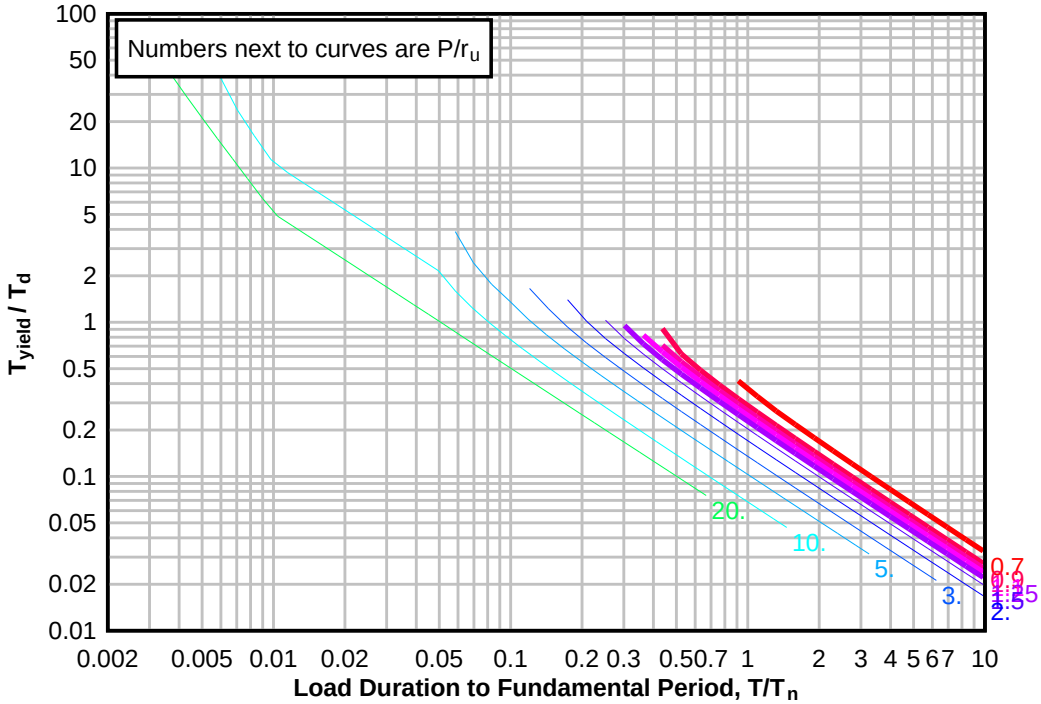


Figure 3-173(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.909, C_2 = 300)

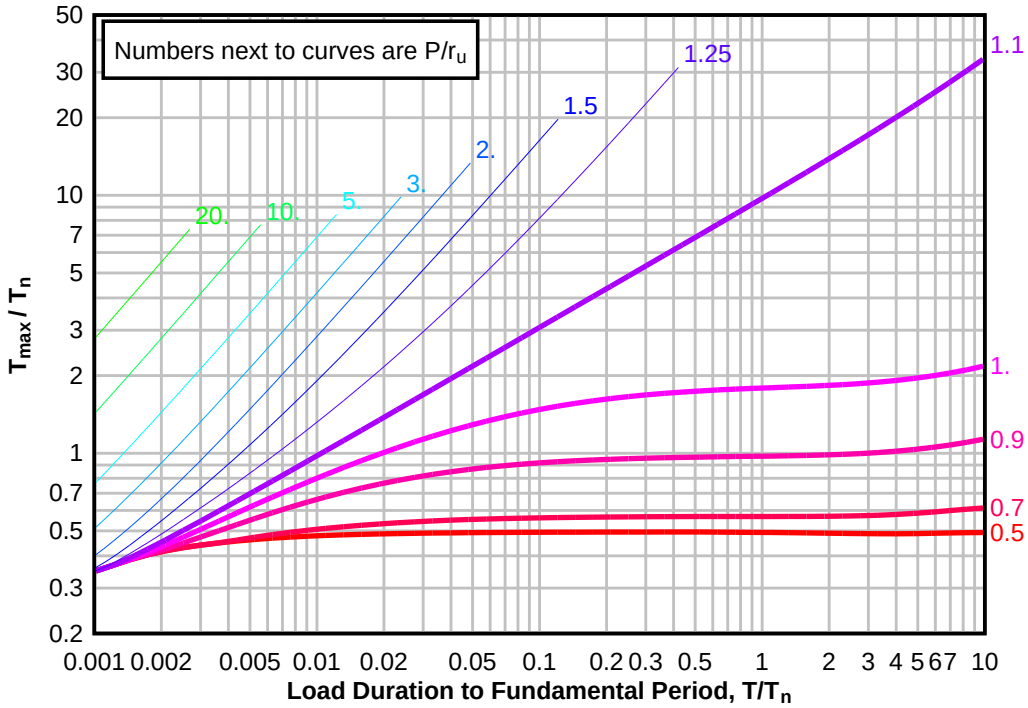


Figure 3-173(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.909, C2 = 300)

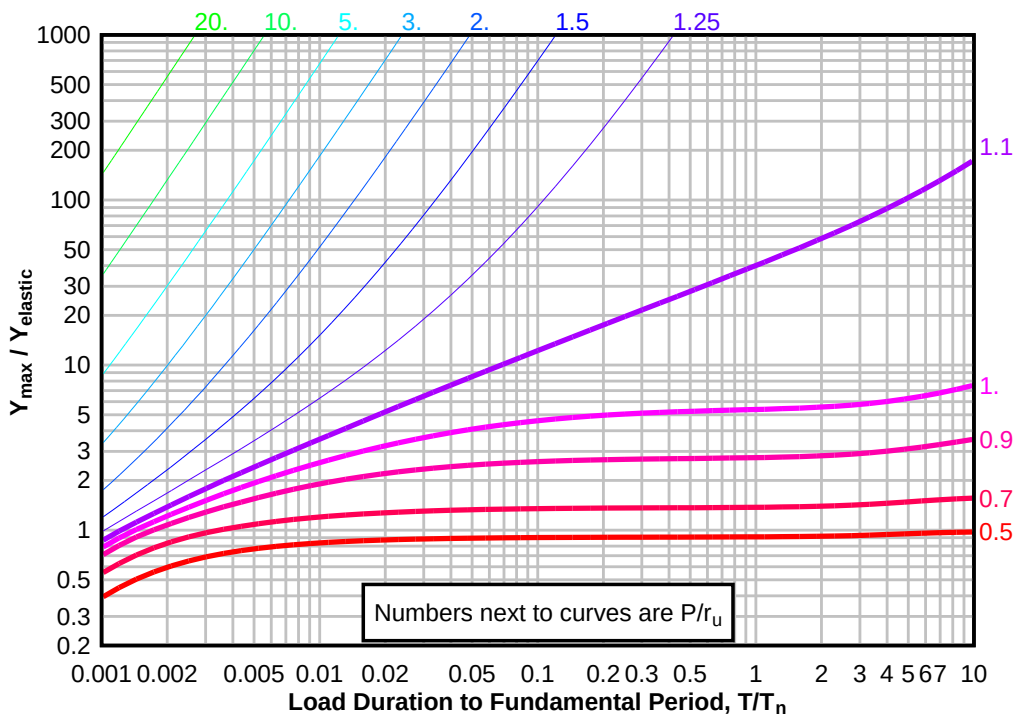


Figure 3-173(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.909, C2 = 300)

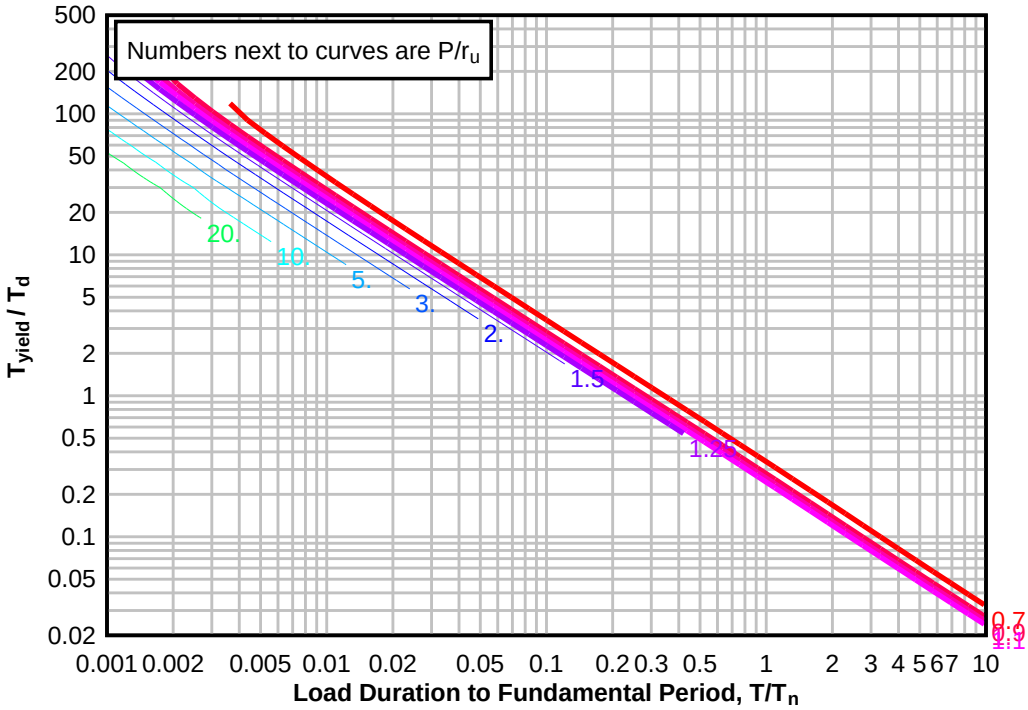


Figure 3-174(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.866, C_2 = 300)

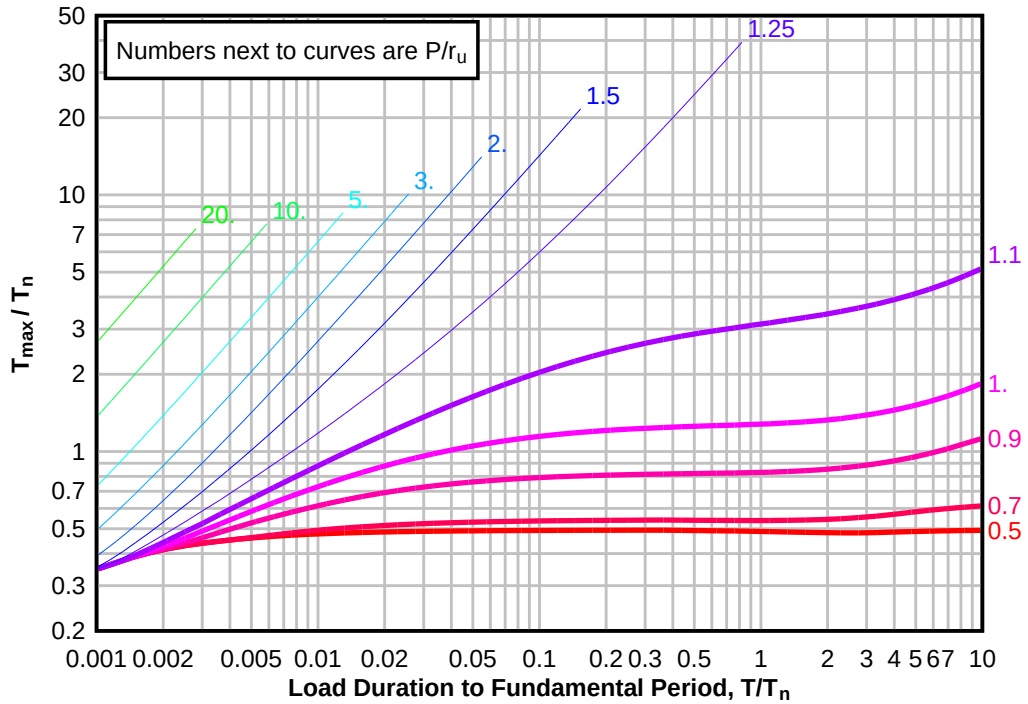


Figure 3-174(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.866, C2 = 300)

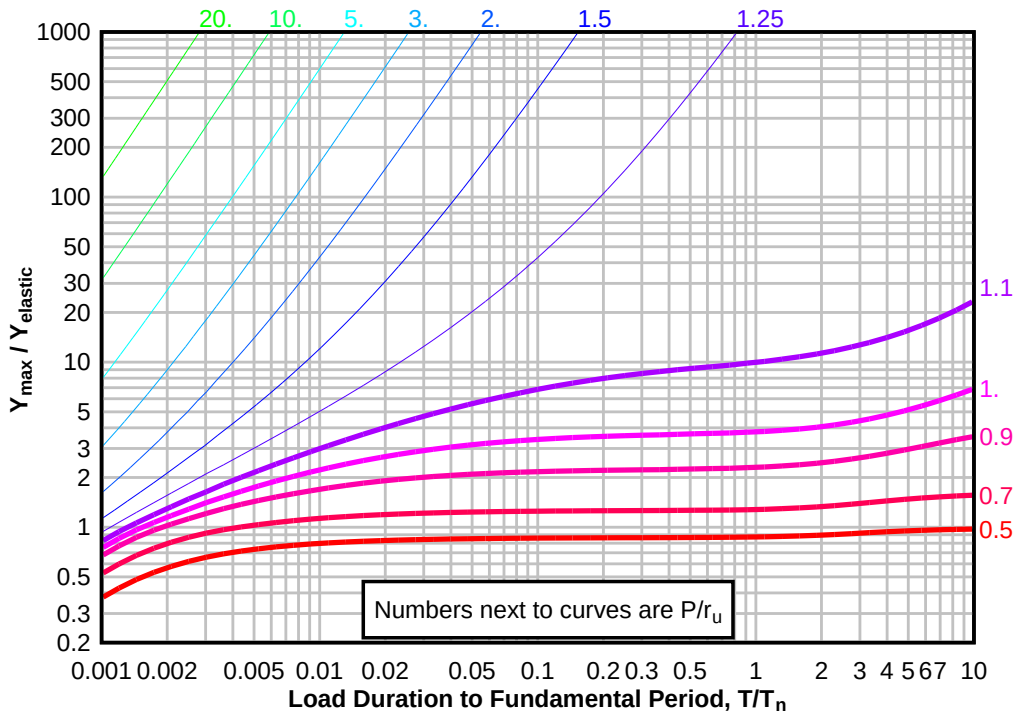


Figure 3-174(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.866, C2 = 300)

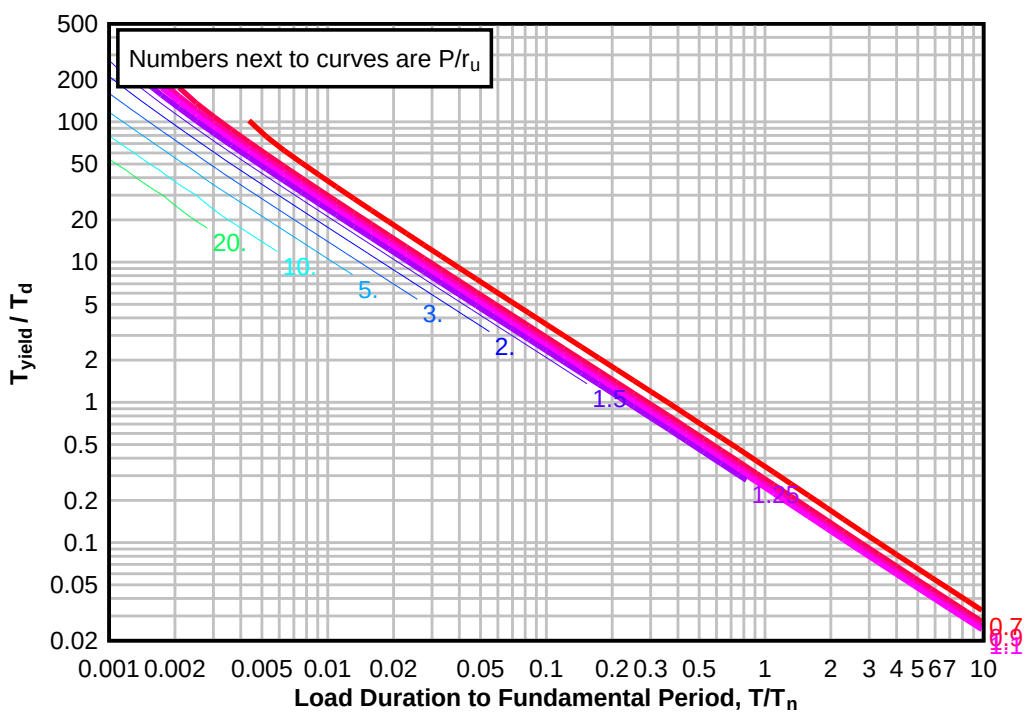


Figure 3-175(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.825, C_2 = 300)

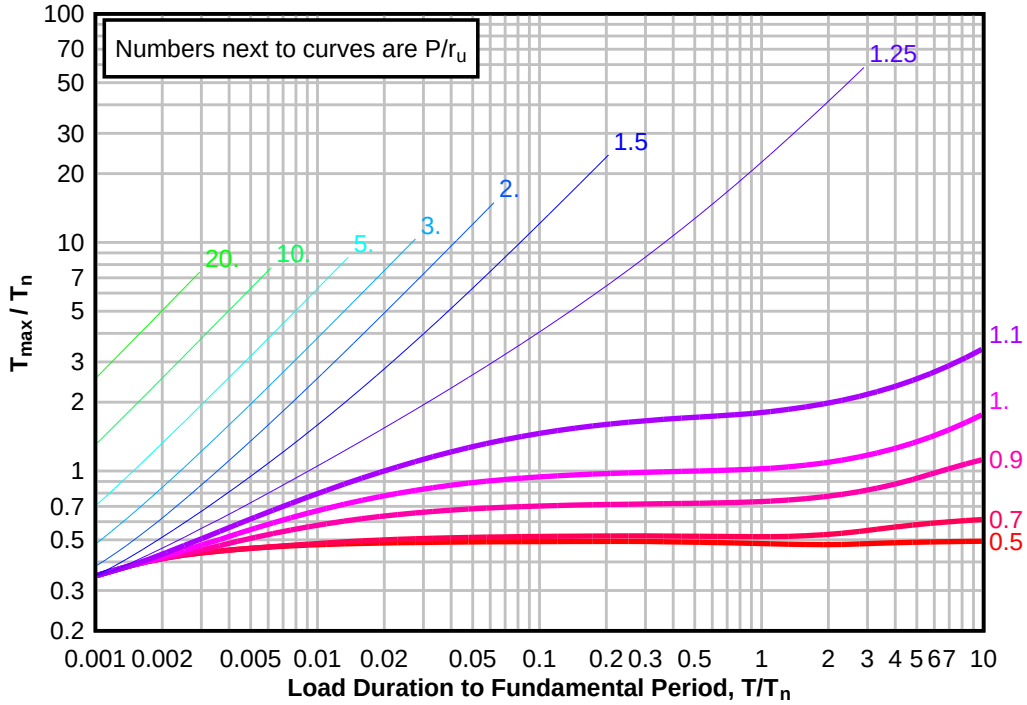


Figure 3-175(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.825, C2 = 300)

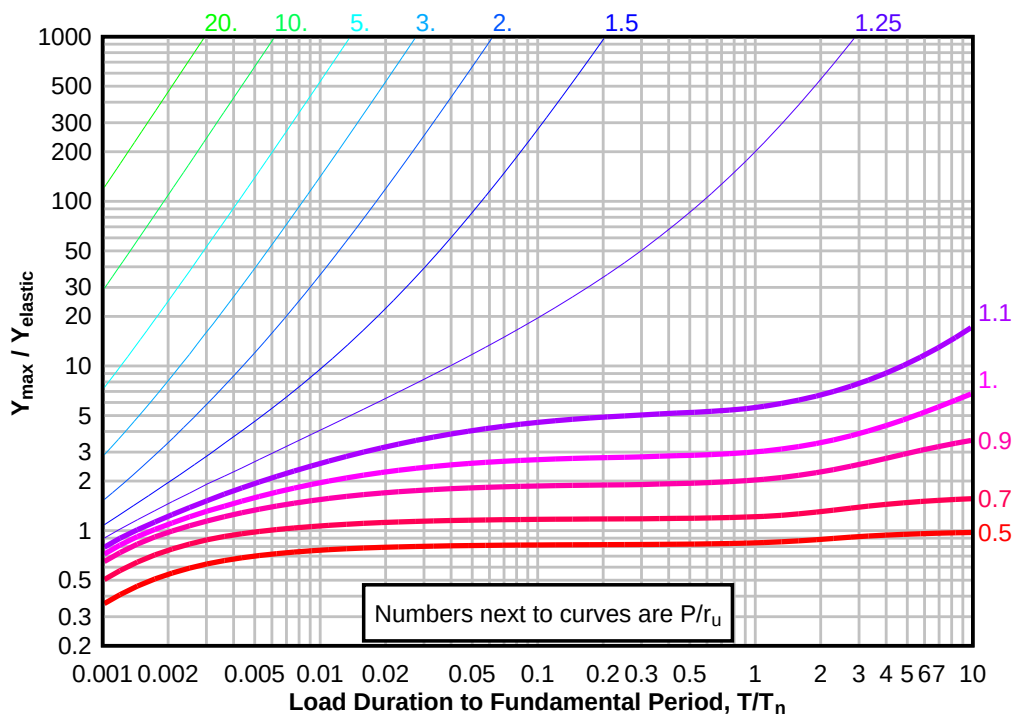


Figure 3-175(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.825, C2 = 300)

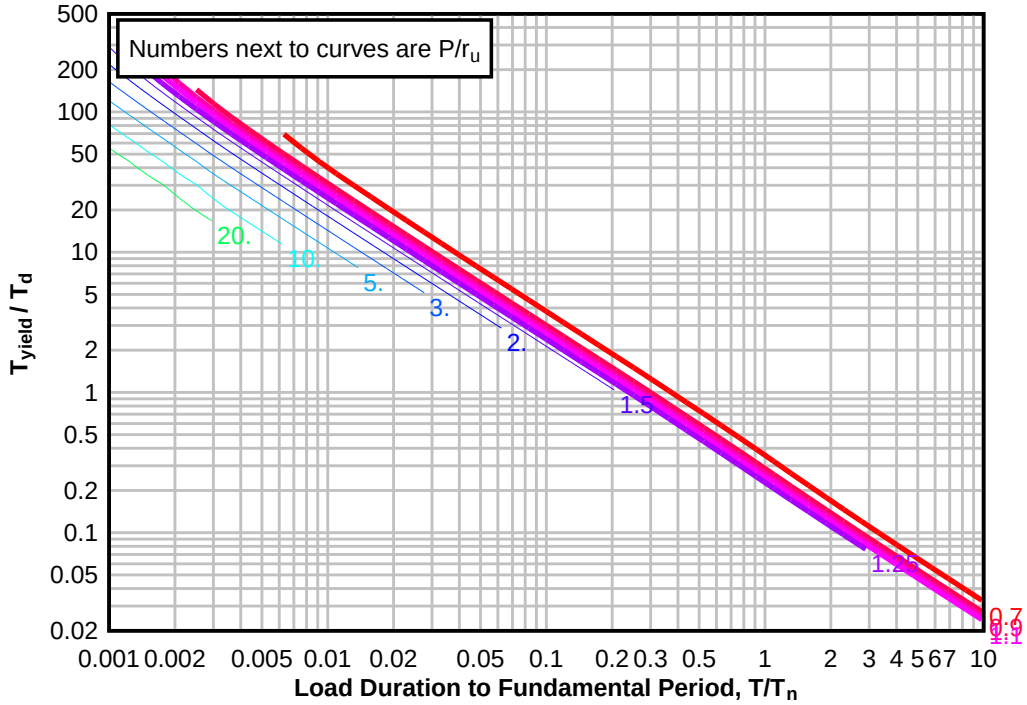


Figure 3-176(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.787, C_2 = 300)

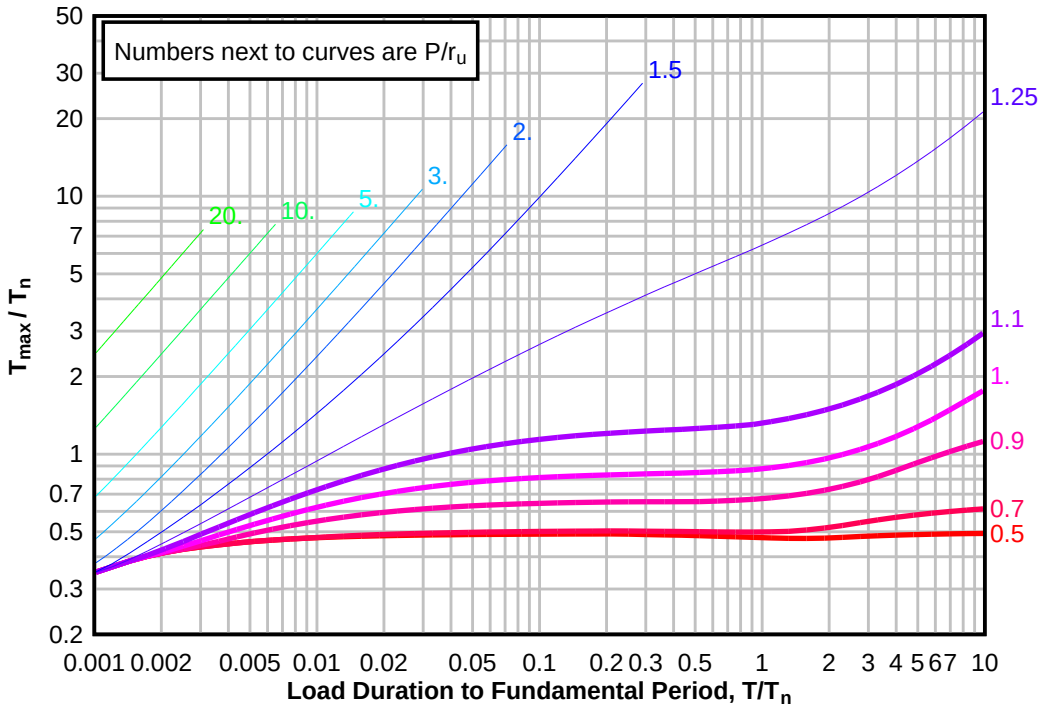


Figure 3-176(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.787, C2 = 300)

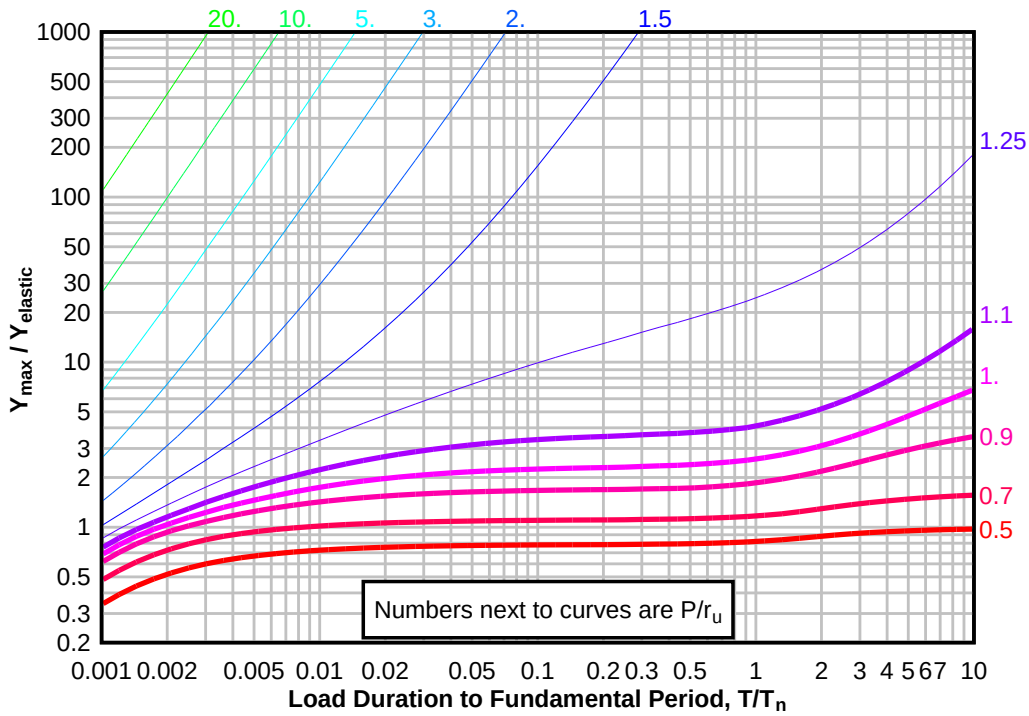


Figure 3-176(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.787, C2 = 300)

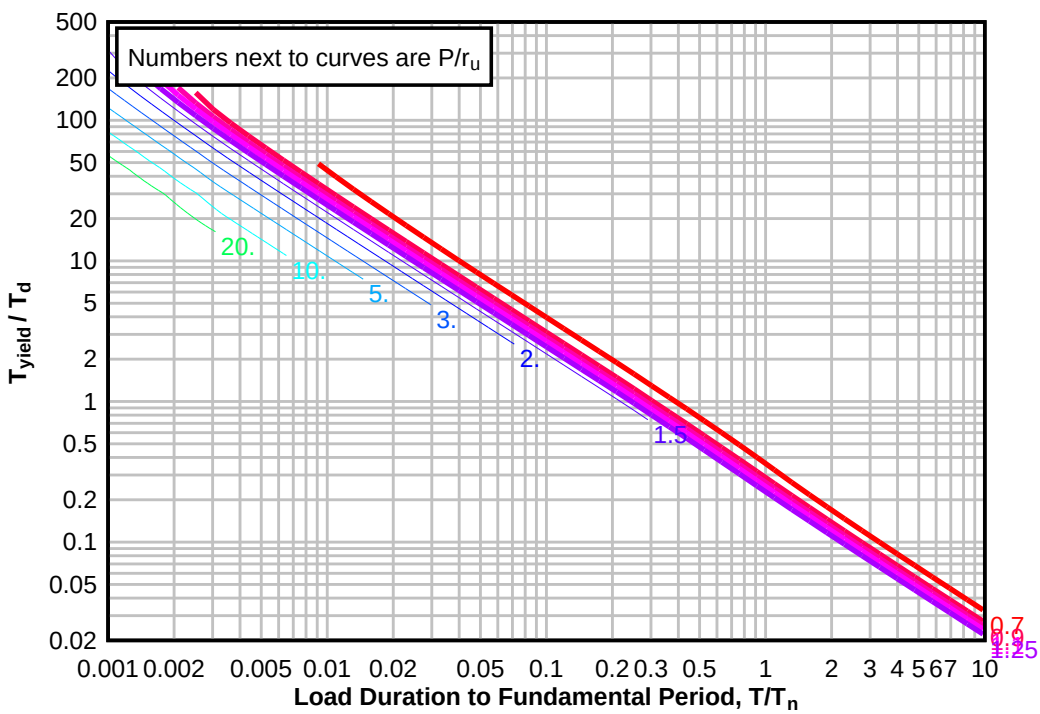


Figure 3-177(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.750, C_2 = 300)

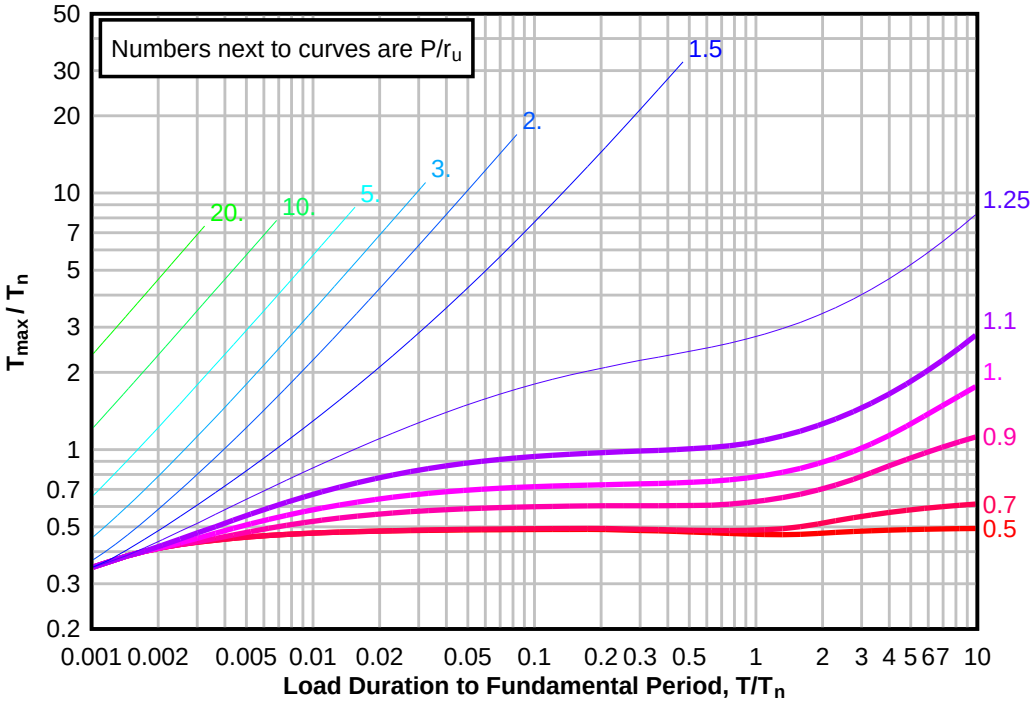


Figure 3-177(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.750, C2 = 300)

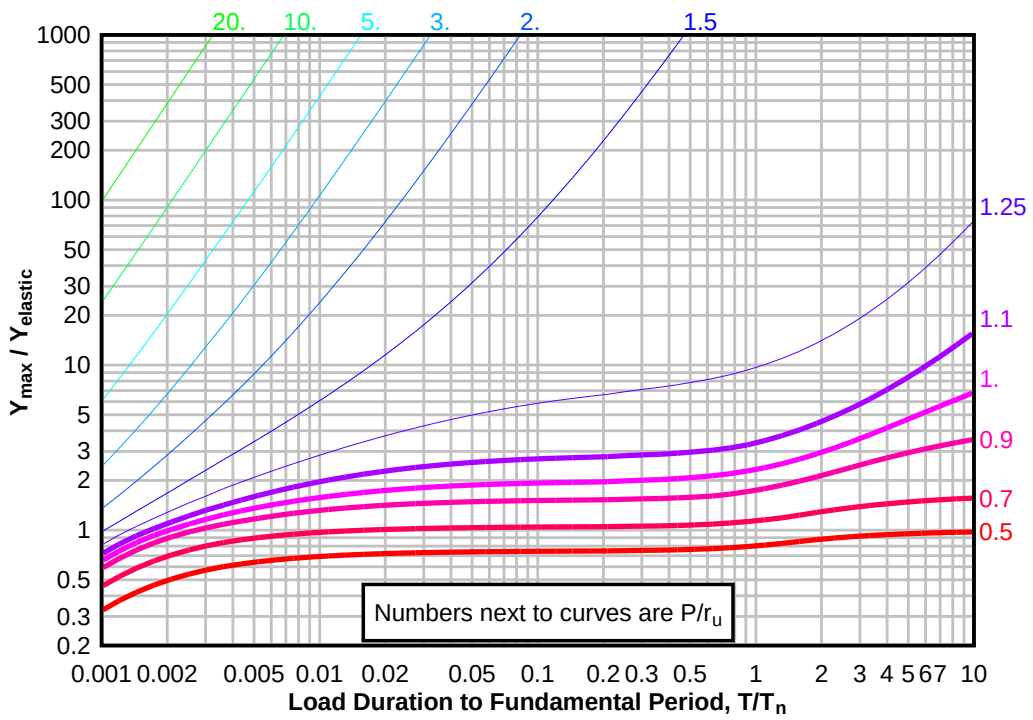


Figure 3-177(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.750, C2 = 300)

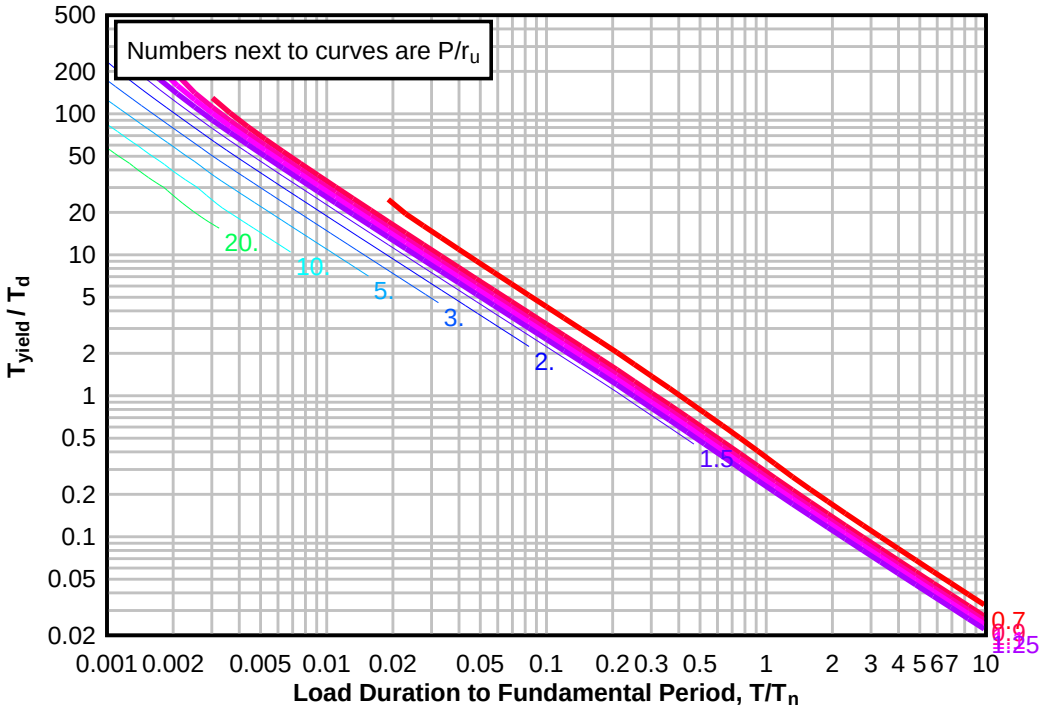


Figure 3-178(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.715, C_2 = 300)

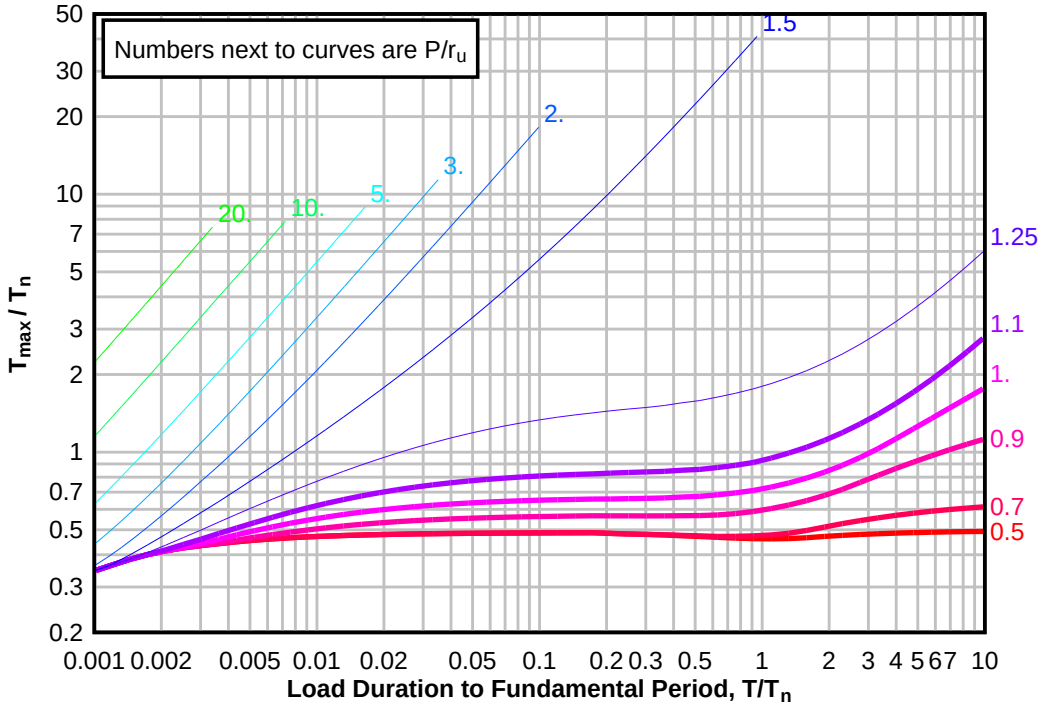


Figure 3-178(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.715, C2 = 300)

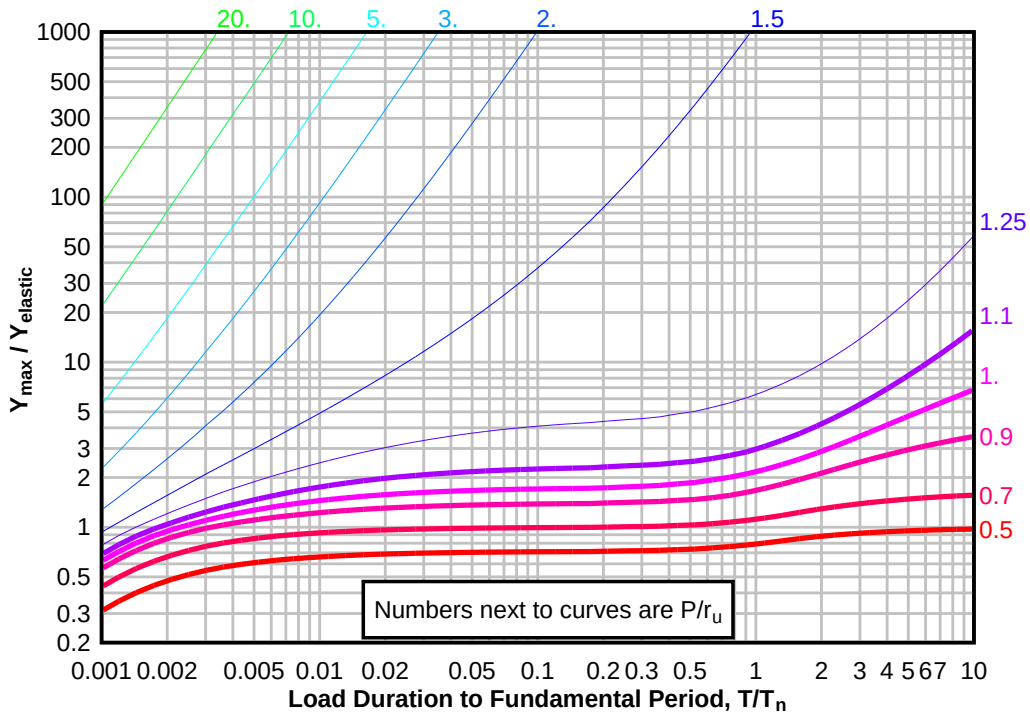


Figure 3-178(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.715, C2 = 300)

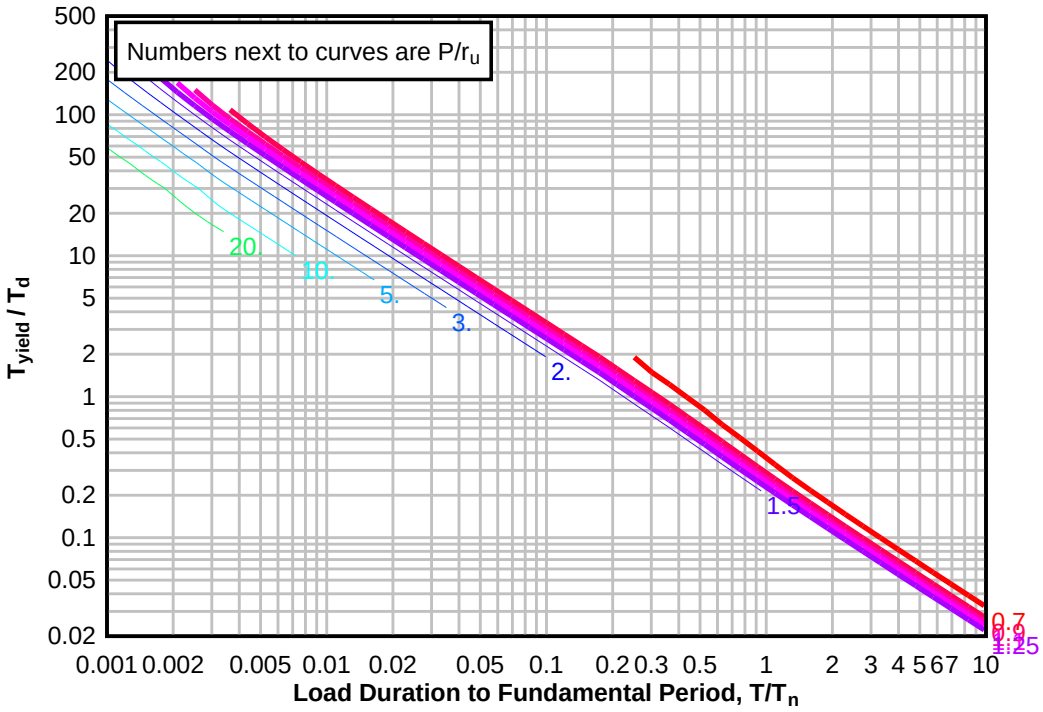


Figure 3-179(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse. (C_1 = 0.681, C_2 = 300)

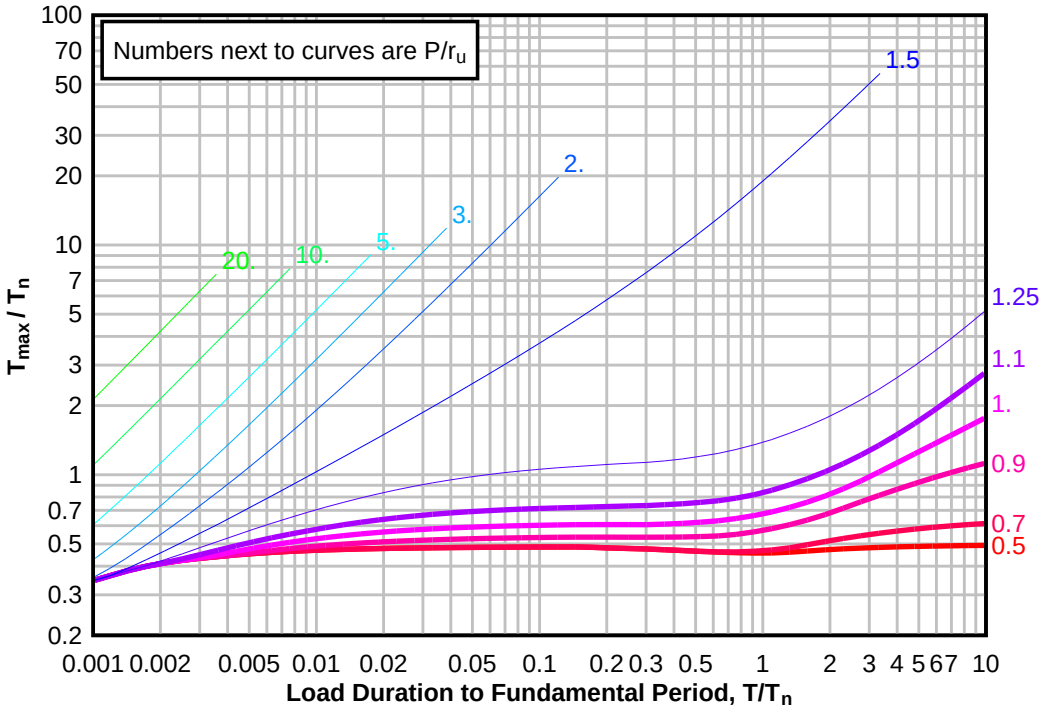


Figure 3-179(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse. (C1 = 0.681, C2 = 300)

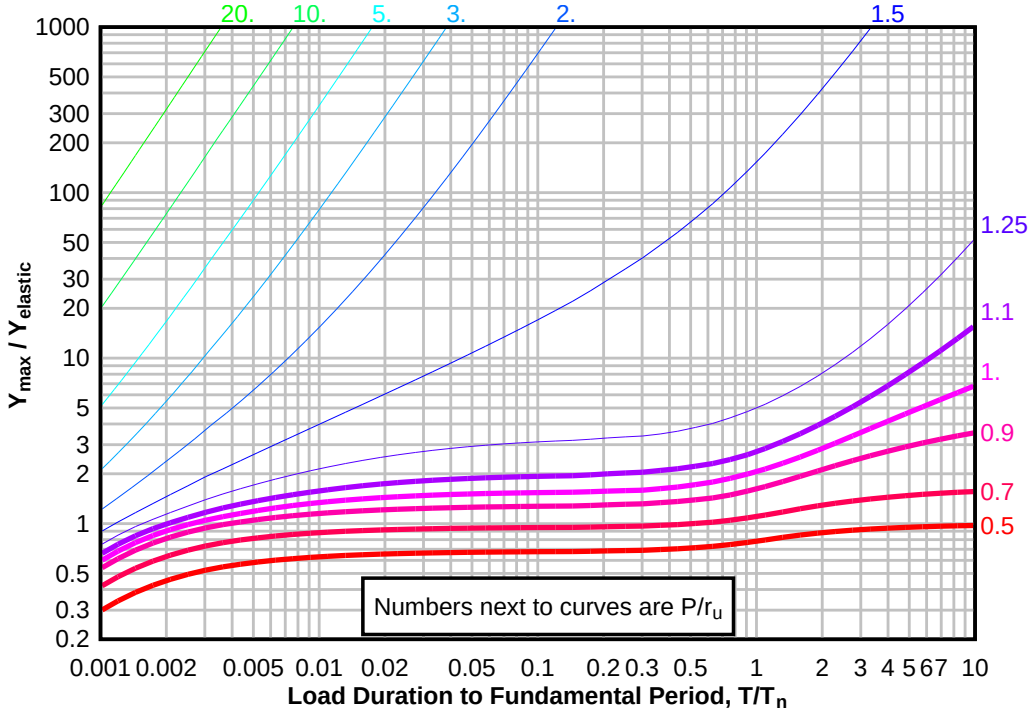


Figure 3-179(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse. (C1 = 0.681, C2 = 300)

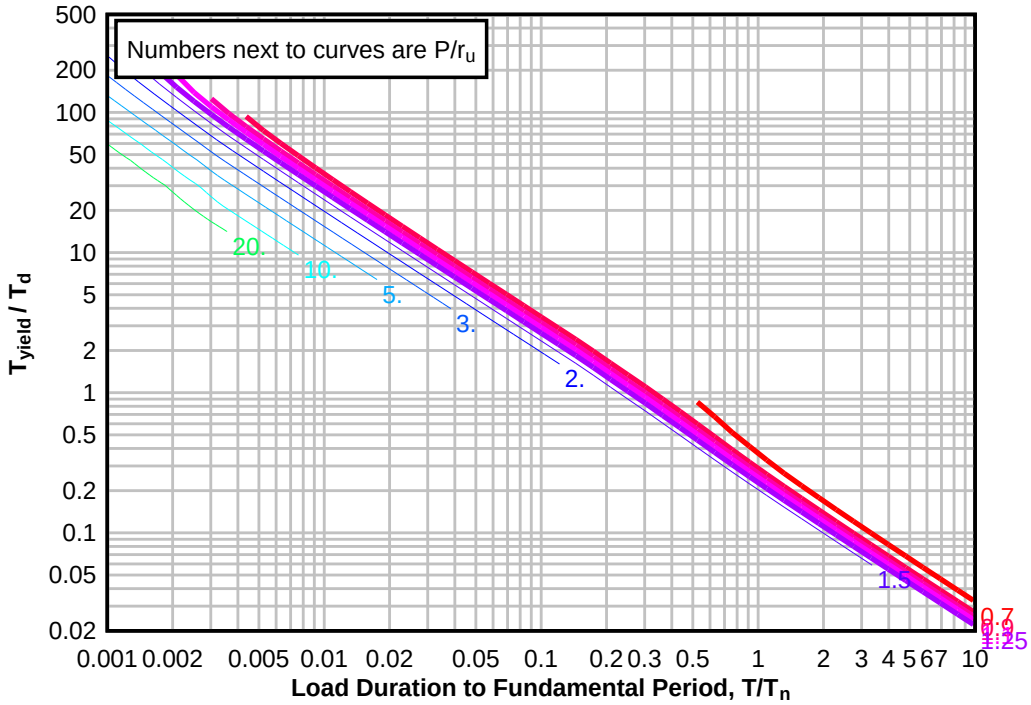


Figure 3-180(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.648, C_2 = 300)

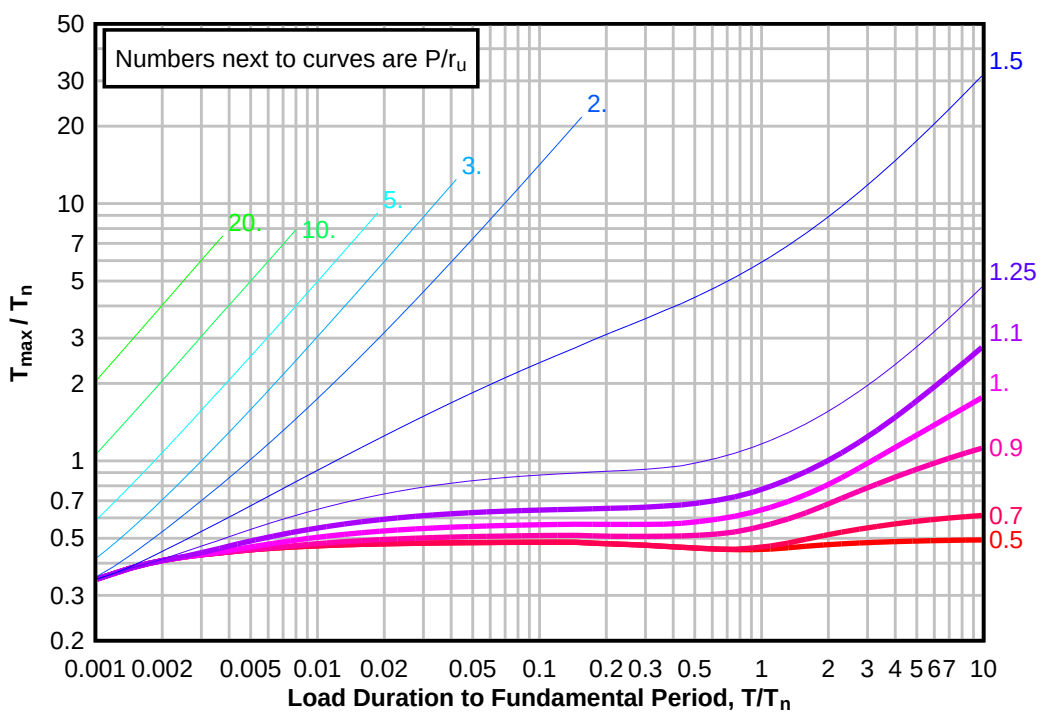


Figure 3-180(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.648, C2 = 300)

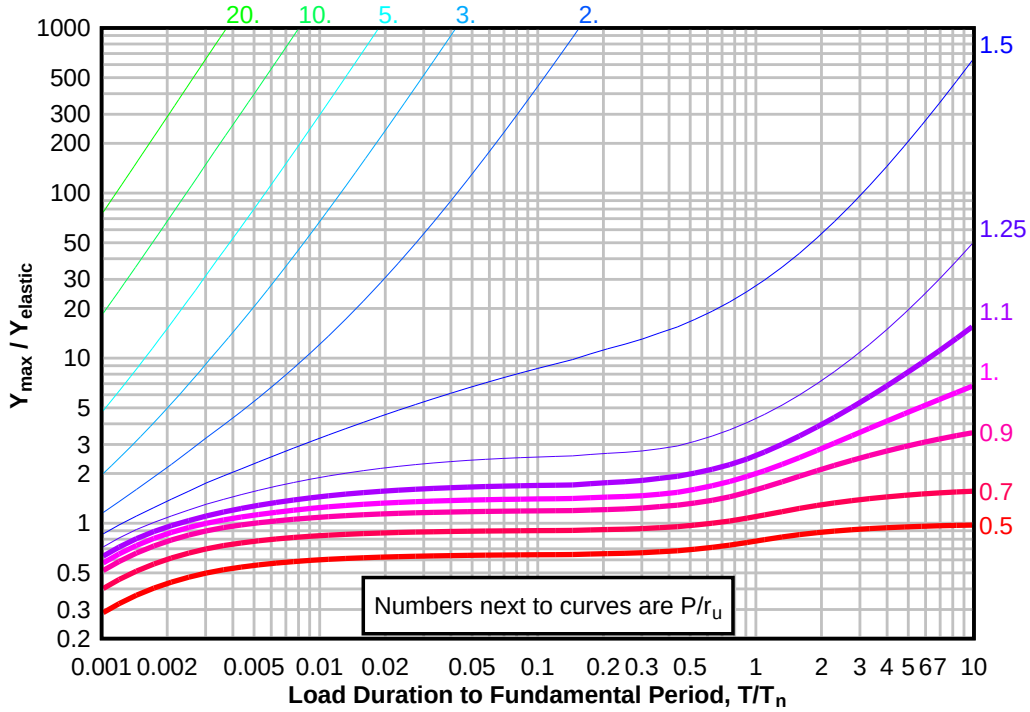


Figure 3-180(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.648, C2 = 300)

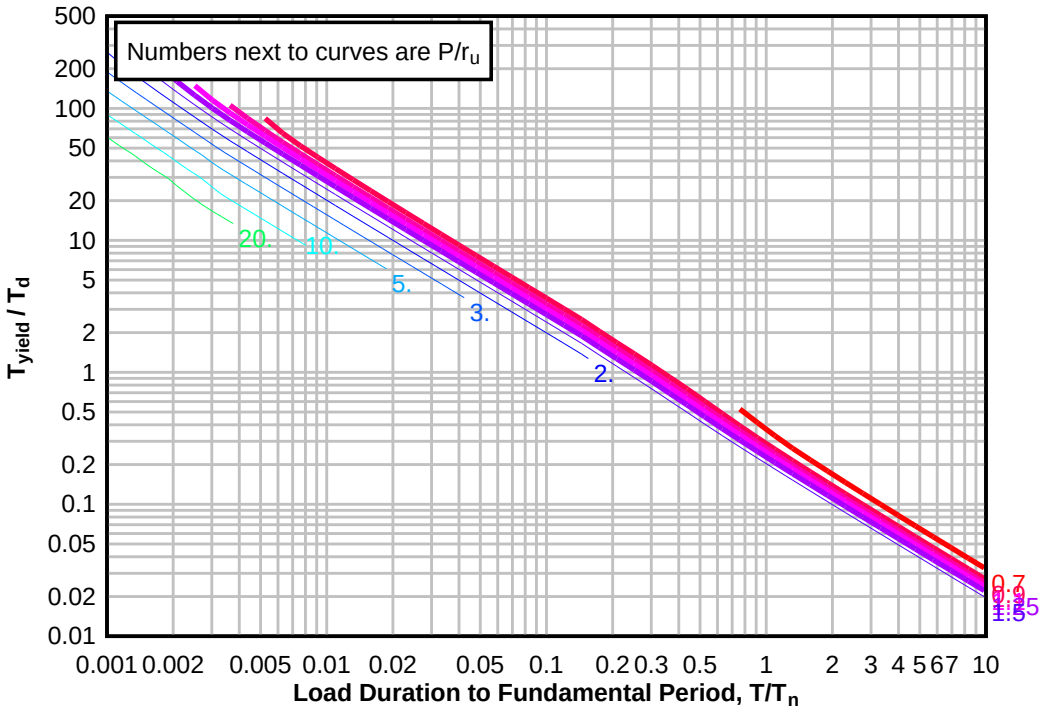


Figure 3-181(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.619, C_2 = 300)

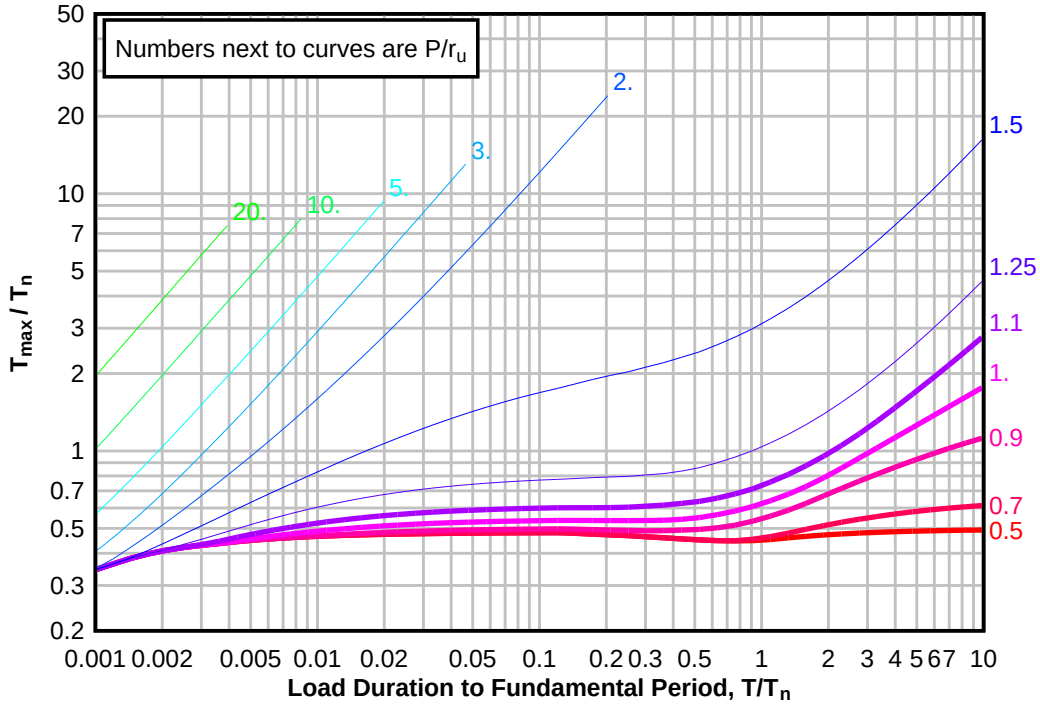


Figure 3-181(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.619, C2 = 300)

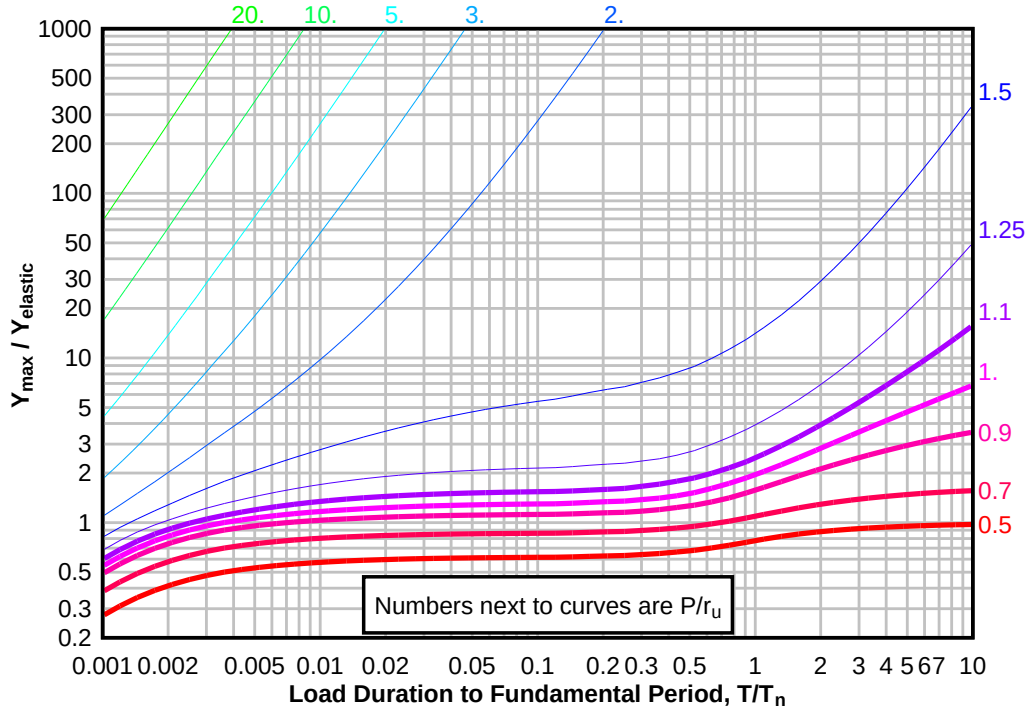


Figure 3-181(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.619, C2 = 300)

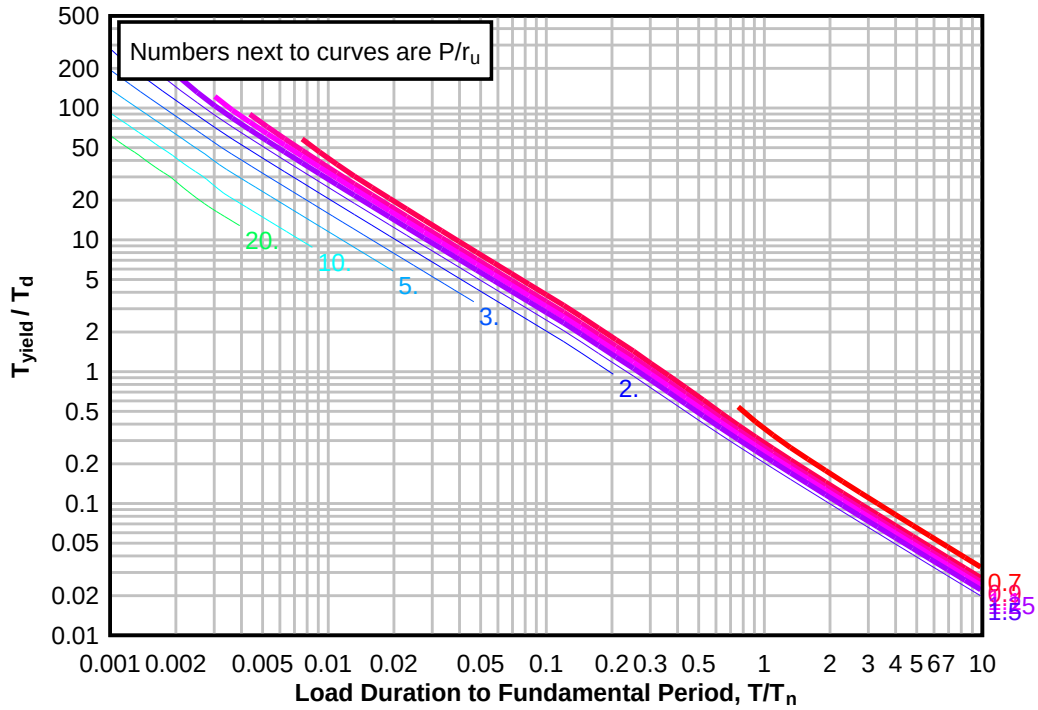


Figure 3-182(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.590, C_2 = 300)

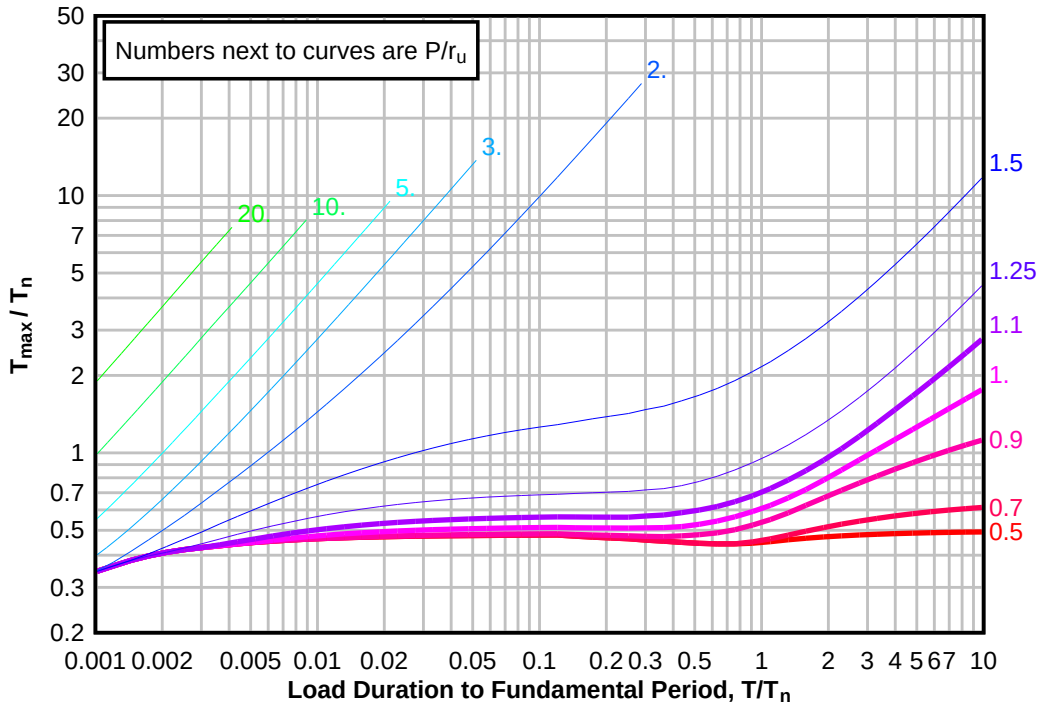


Figure 3-182(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.590, C2 = 300)

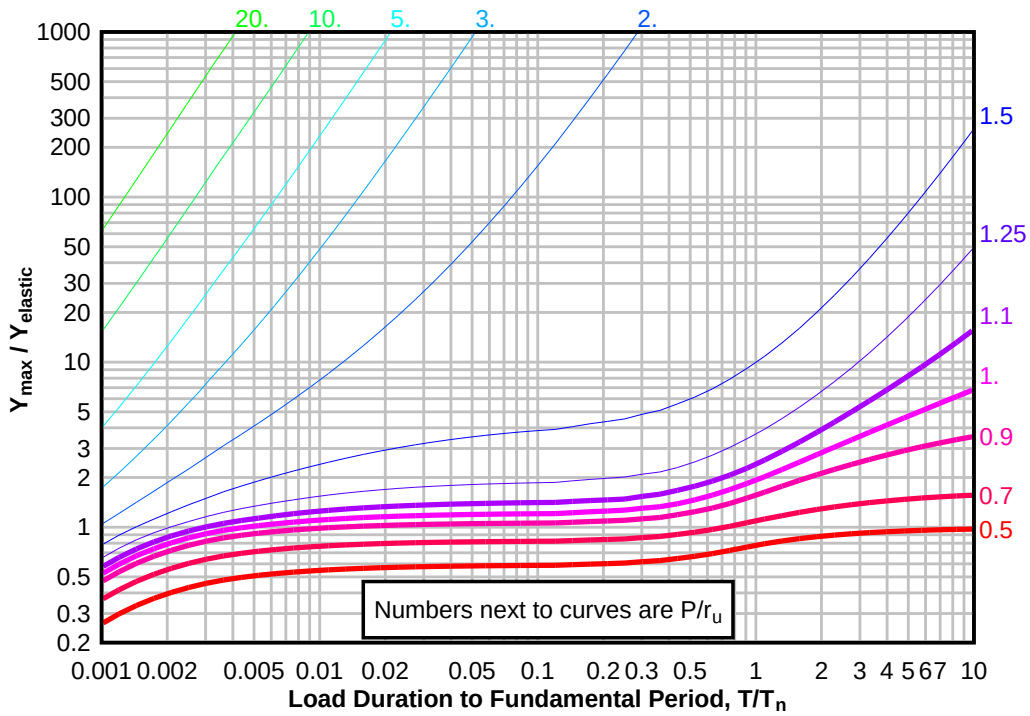


Figure 3-182(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.590, C2 = 300)

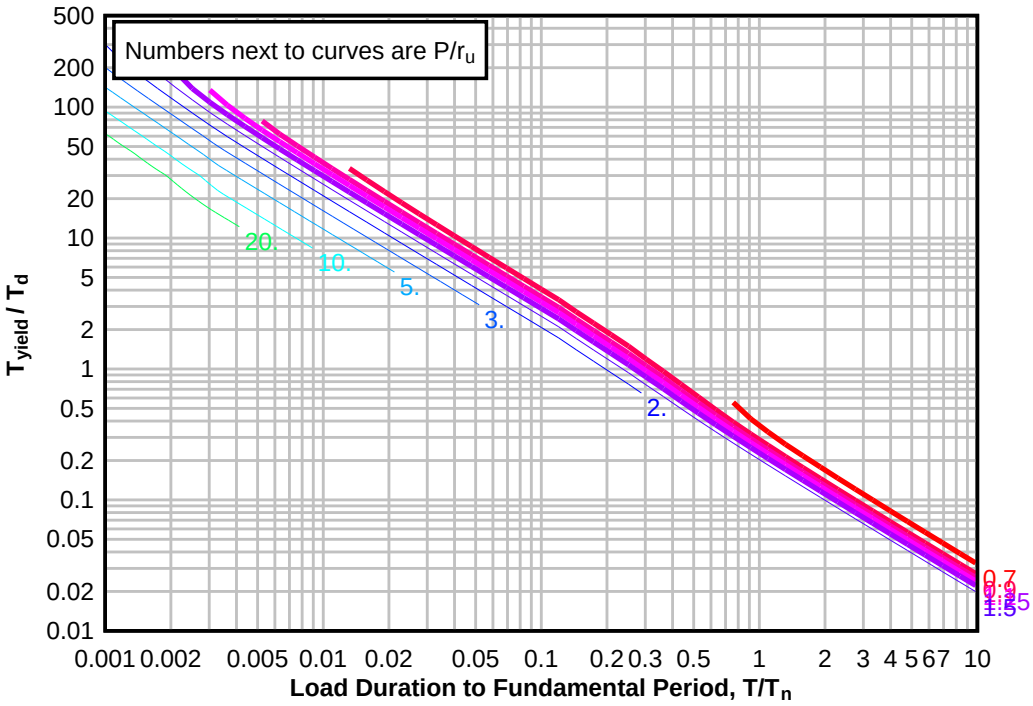


Figure 3-183(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.562, C_2 = 300)

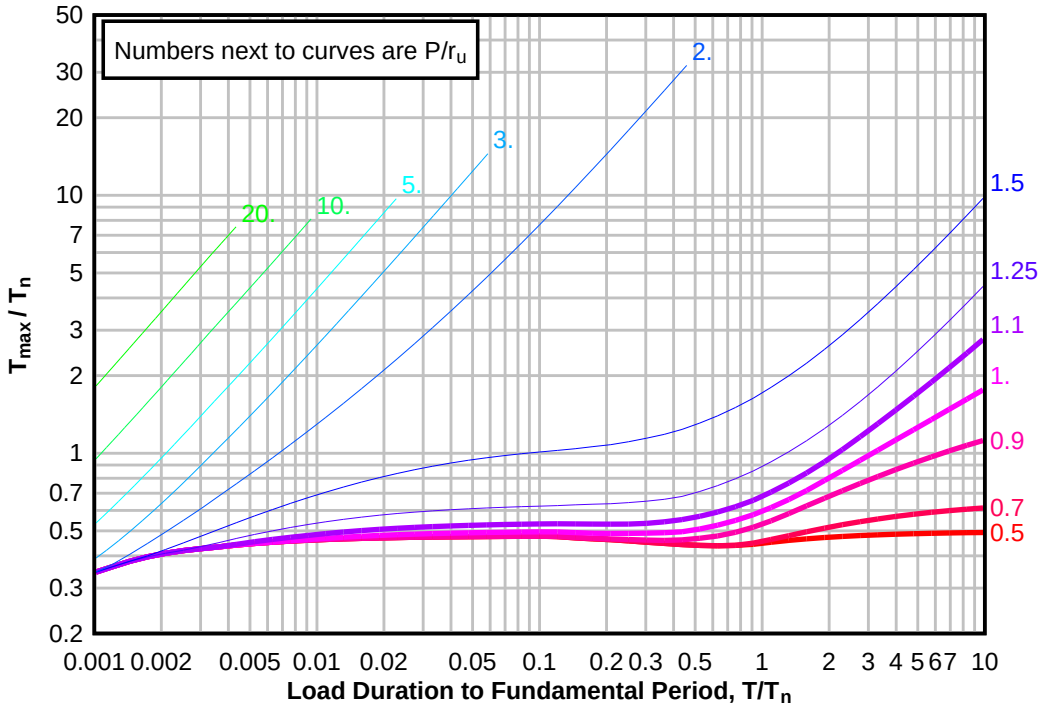


Figure 3-183(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.562, C2 = 300)

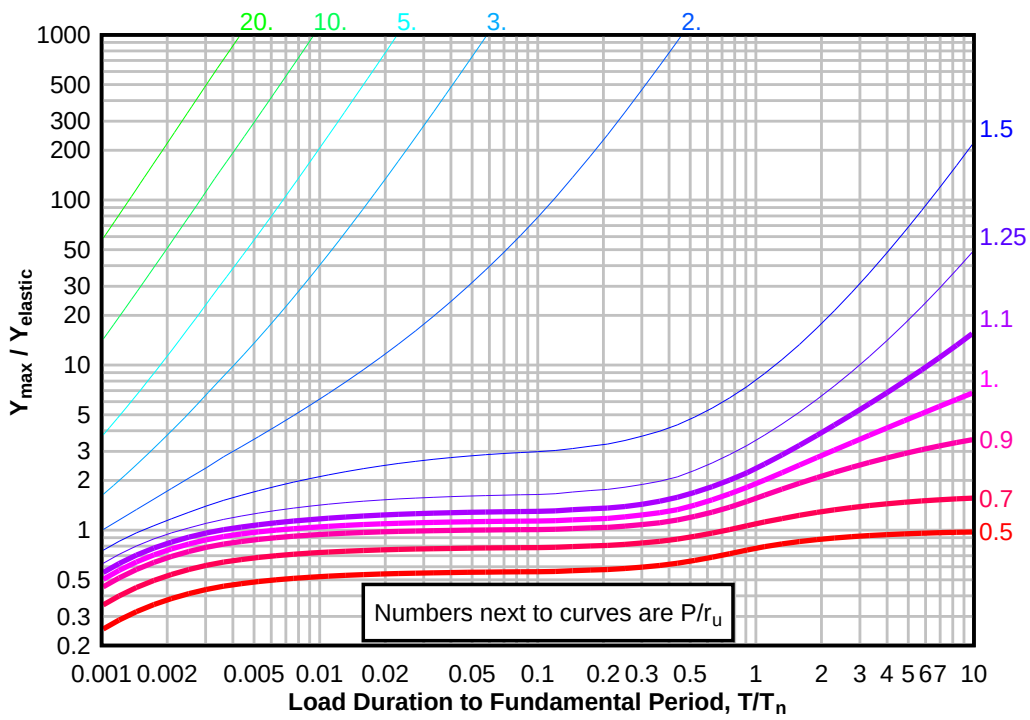


Figure 3-183(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.562, C2 = 300)

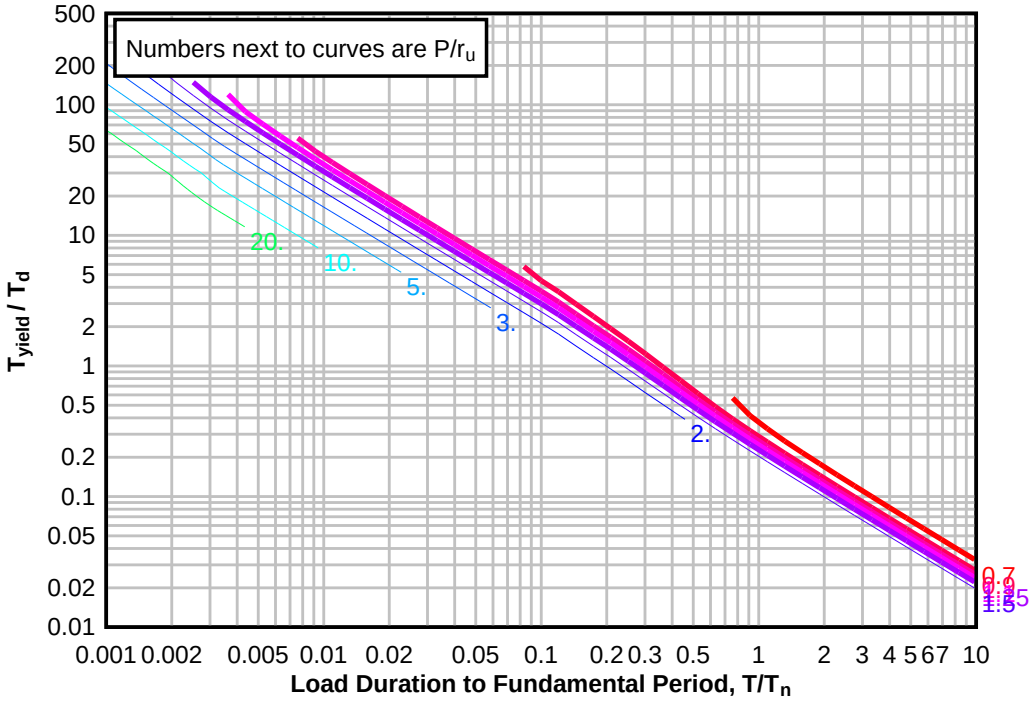


Figure 3-184(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.536, C_2 = 300)

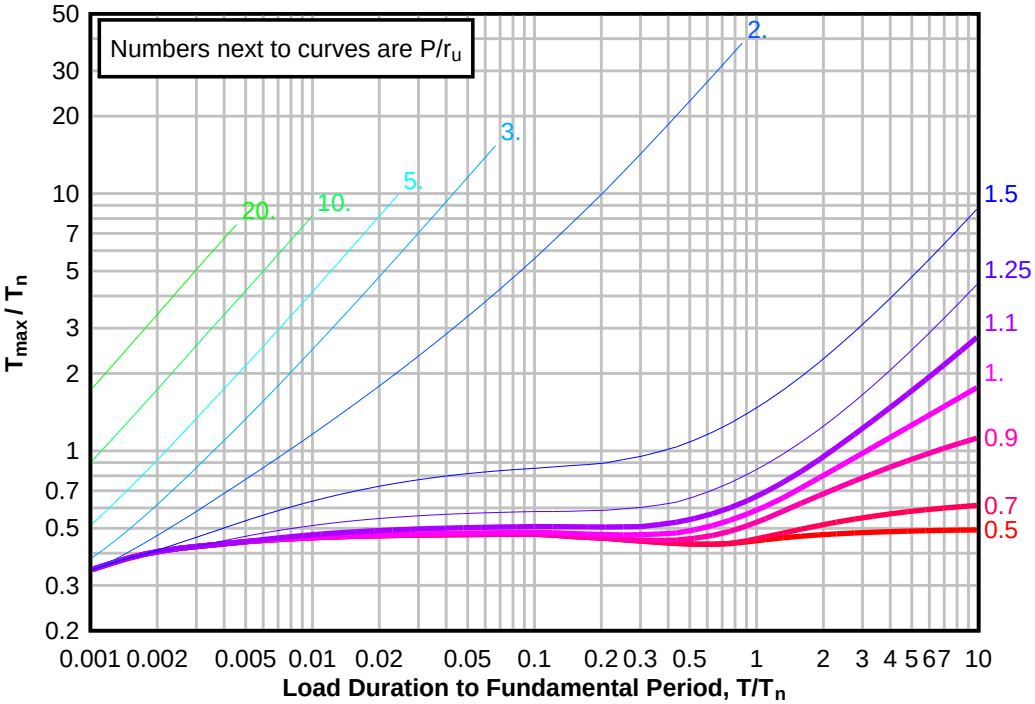


Figure 3-184(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.536, C2 = 300)

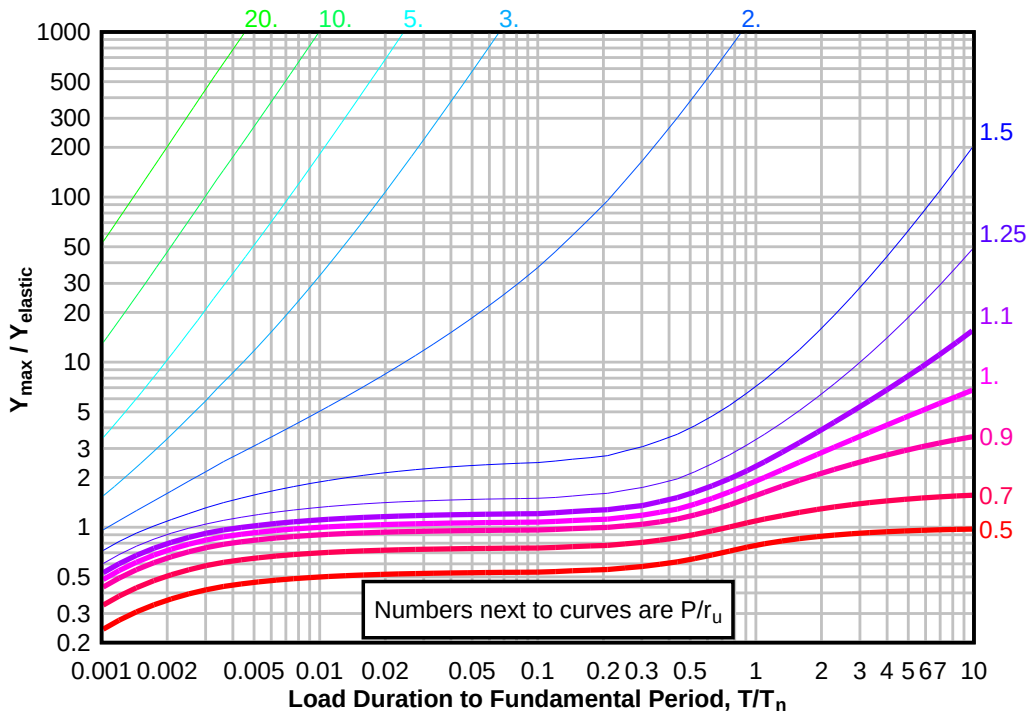


Figure 3-184(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.536, C2 = 300)

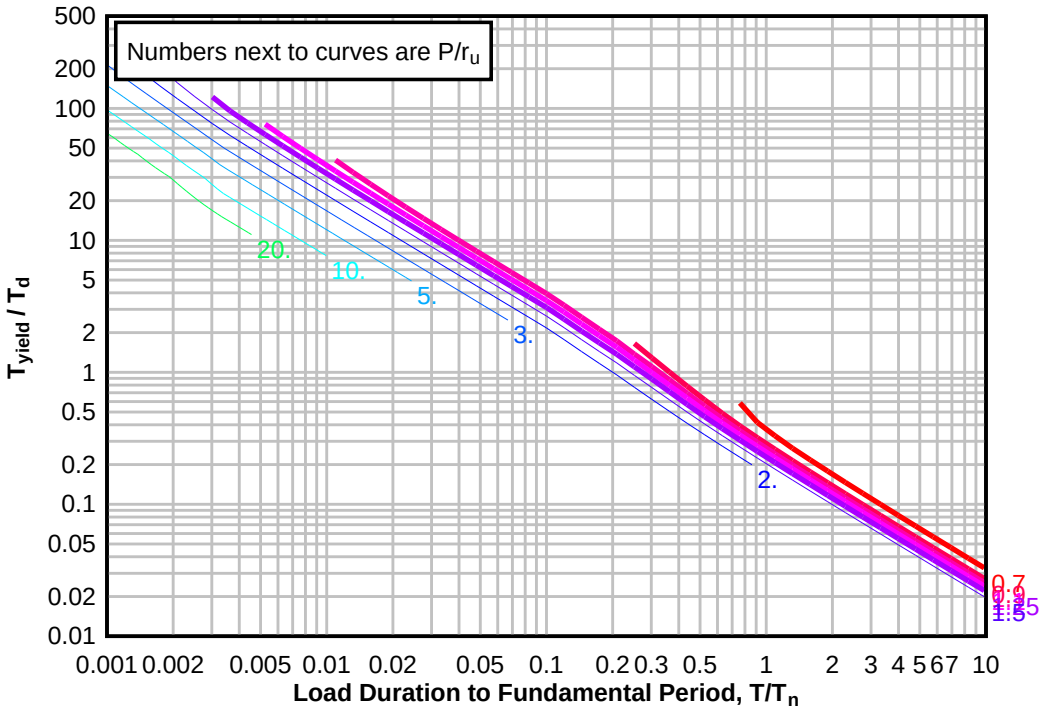


Figure 3-185(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.511, C_2 = 300)

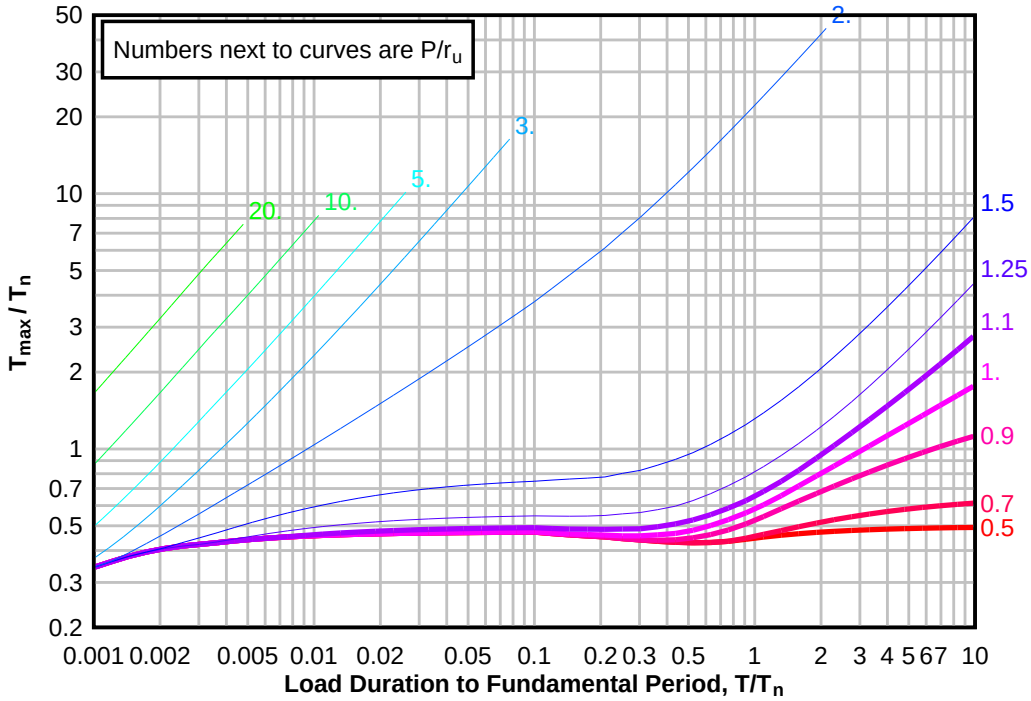


Figure 3-185(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.511, C2 = 300)

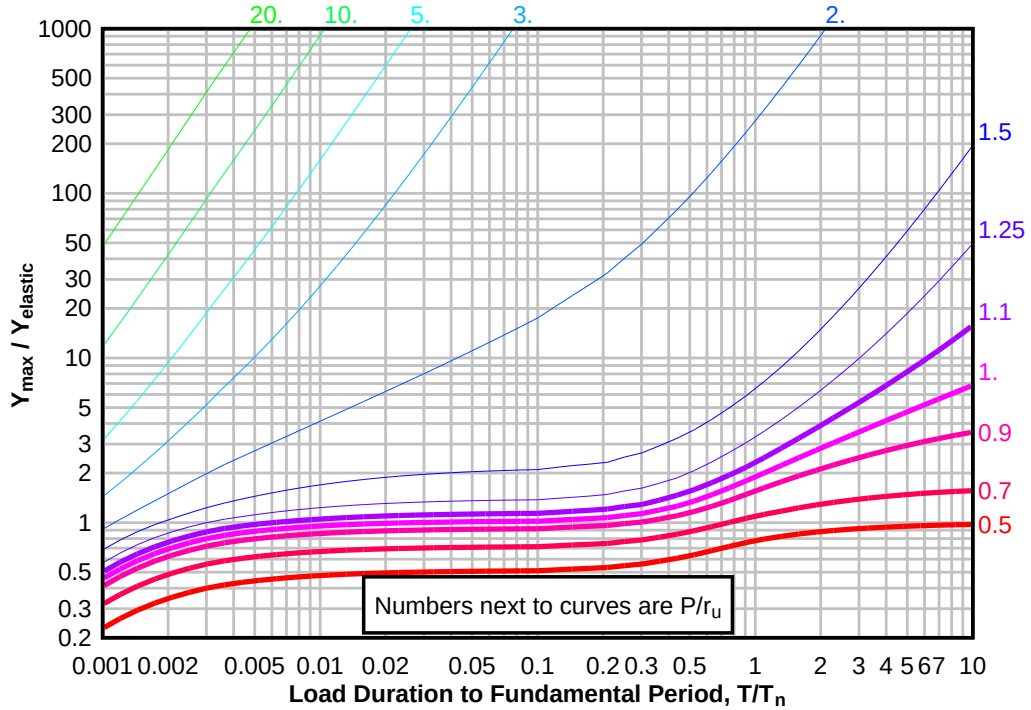


Figure 3-185(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.511, C2 = 300)

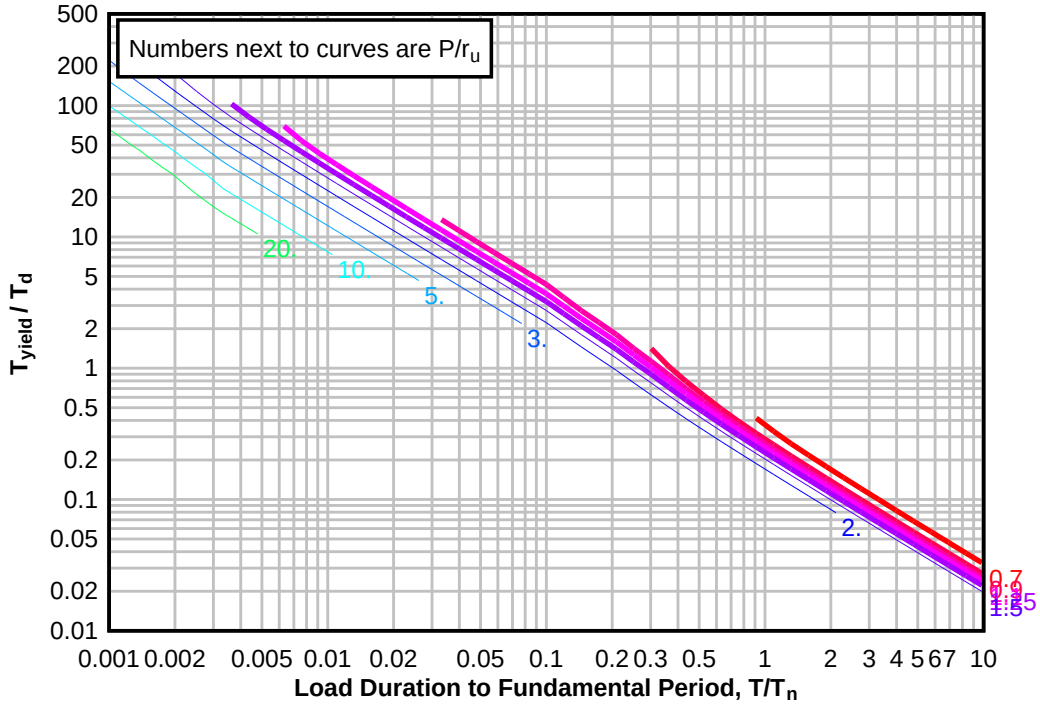


Figure 3-186(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.487, C_2 = 300)

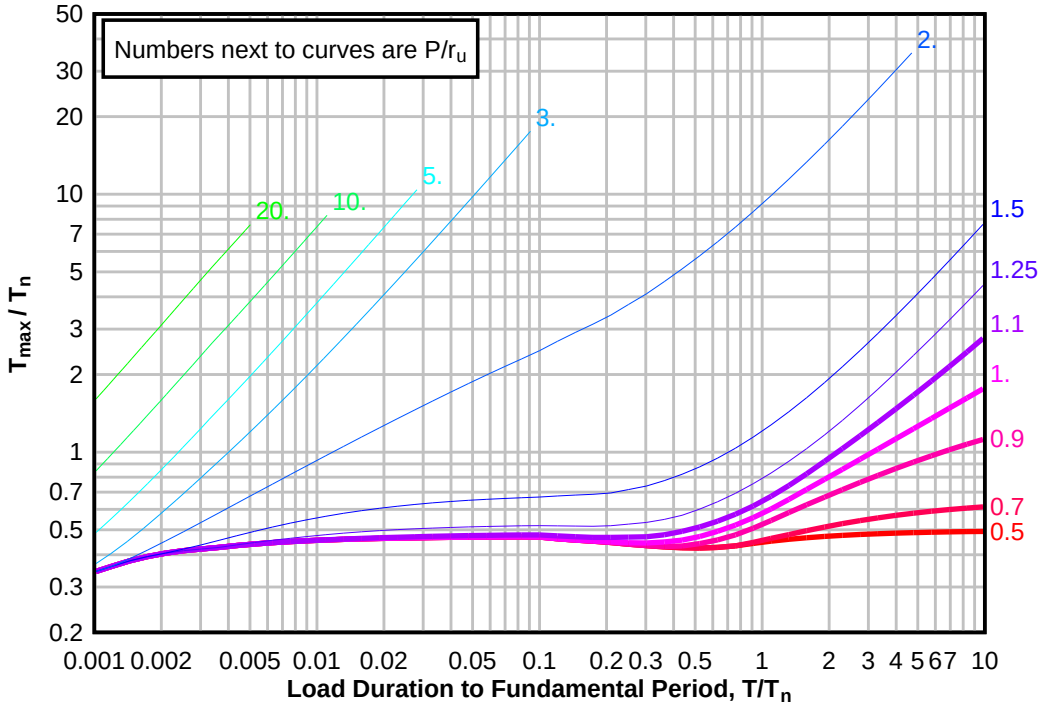


Figure 3-186(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.487, C2 = 300)

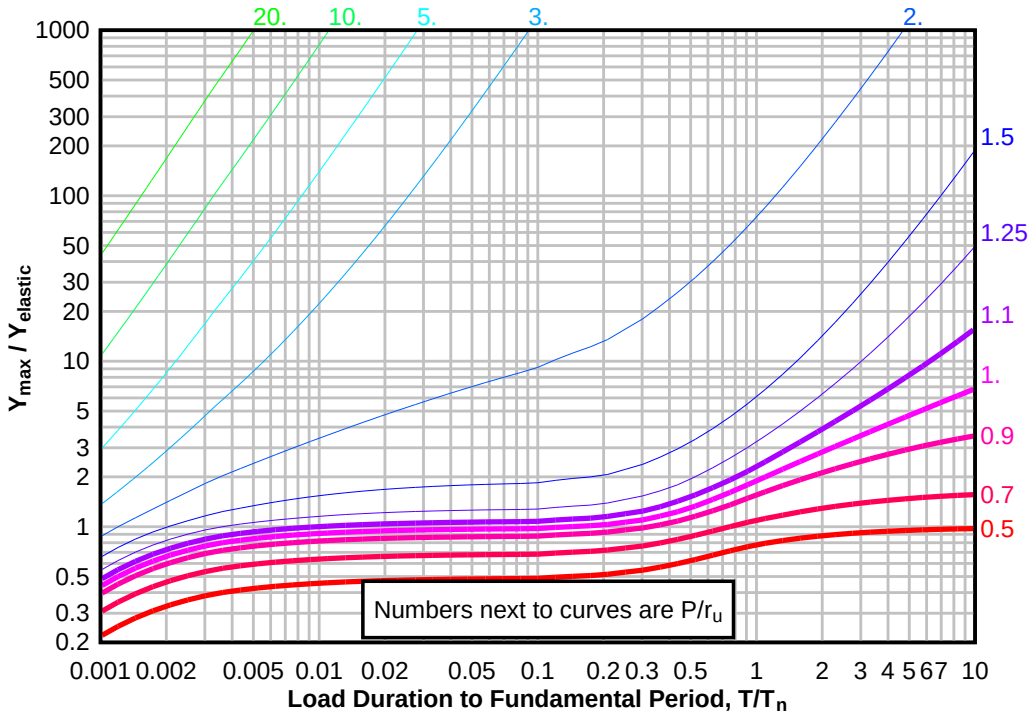


Figure 3-186(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.487, C2 = 300)

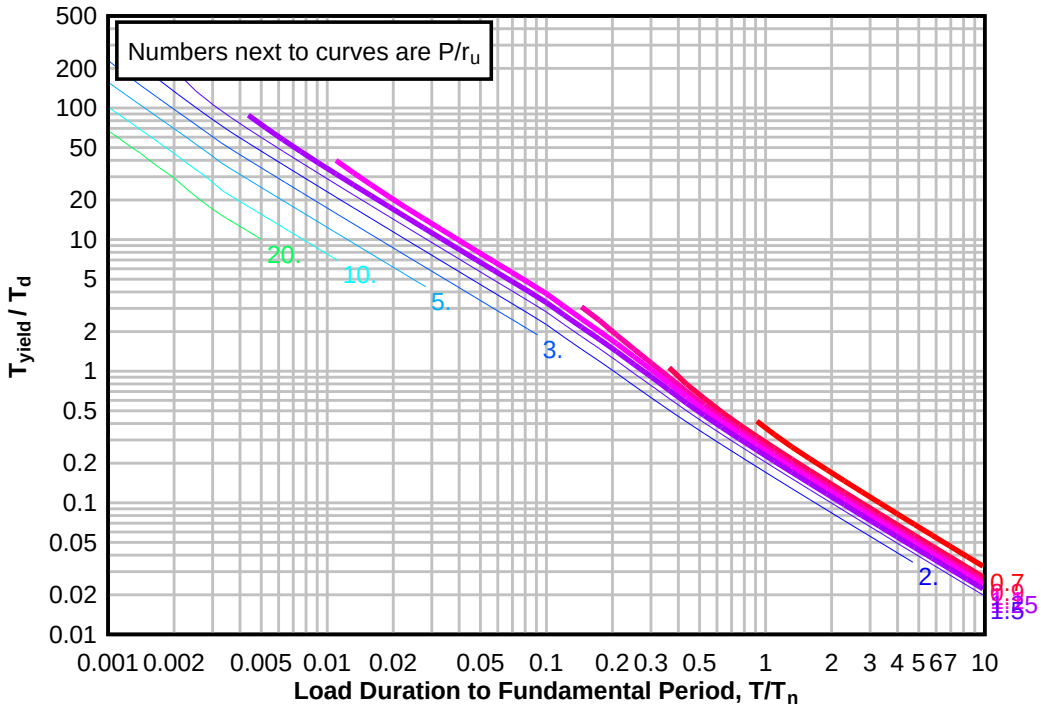


Figure 3-187(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.464, C_2 = 300)

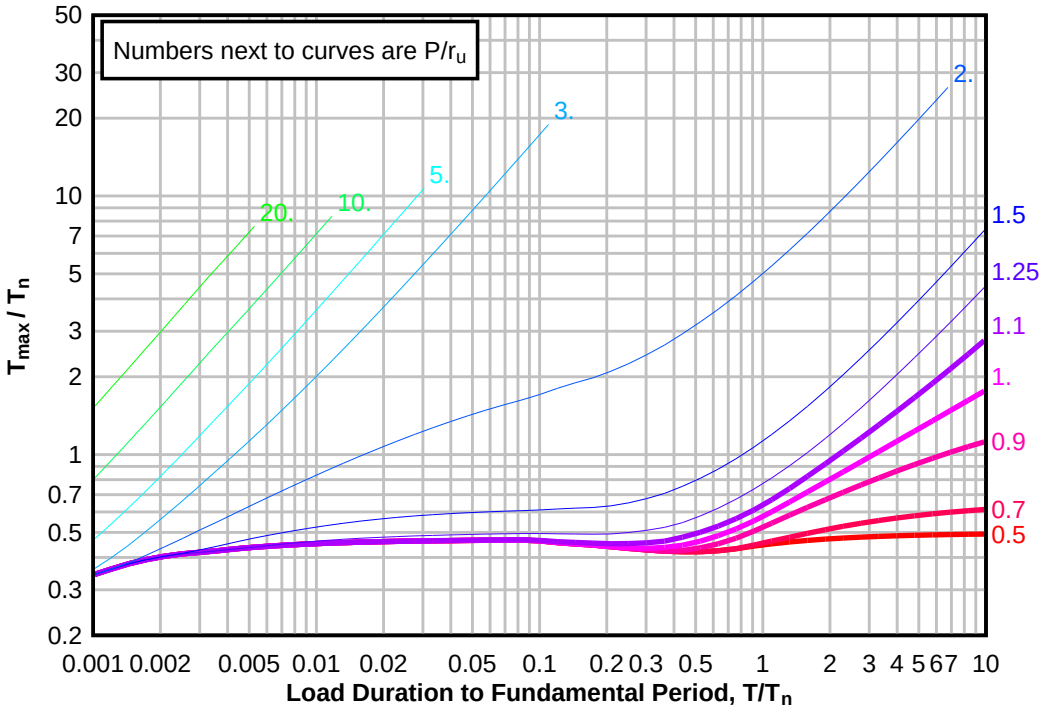


Figure 3-187(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.464, C2 = 300)

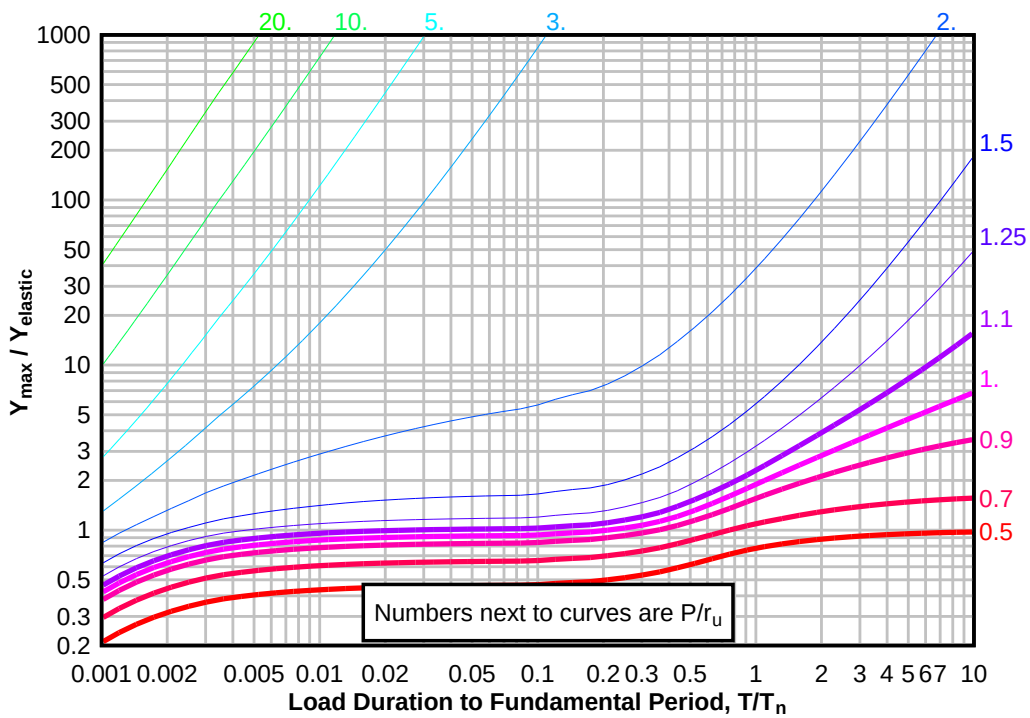


Figure 3-187(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.464, C2 = 300)

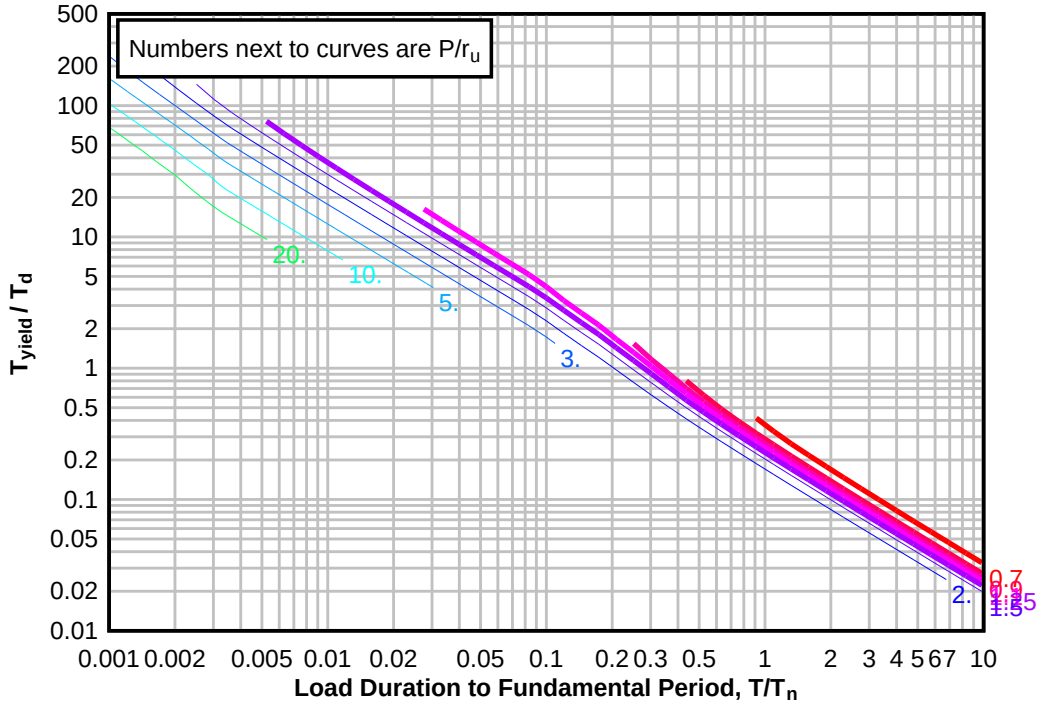


Figure 3-188(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.422, C_2 = 300)

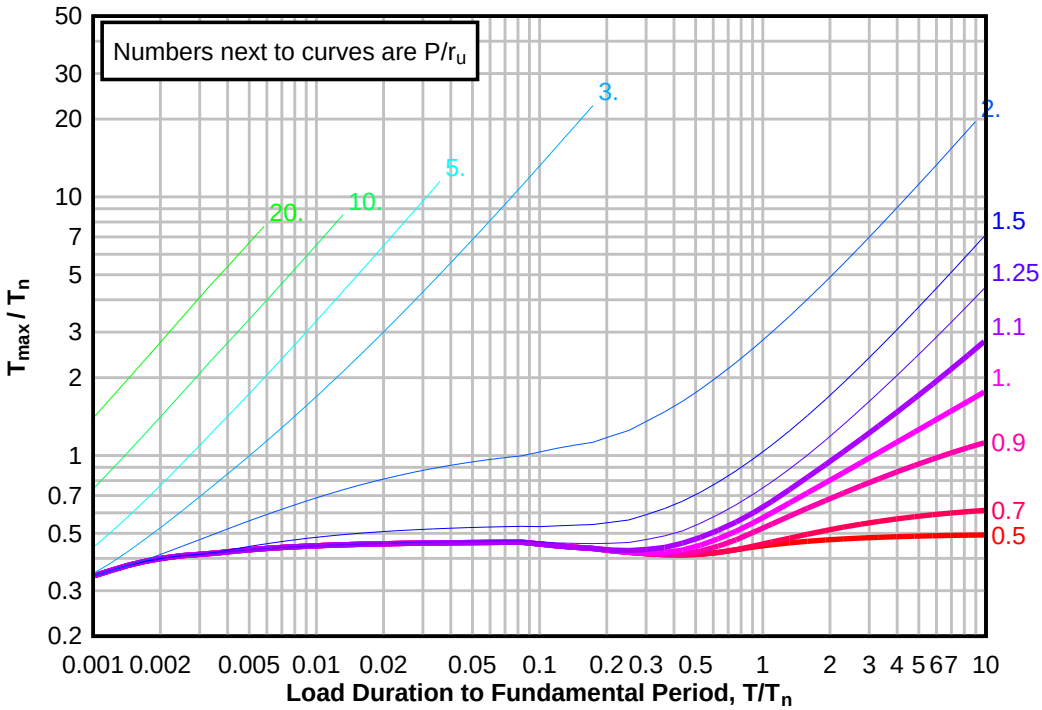


Figure 3-188(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.422, C2 = 300)

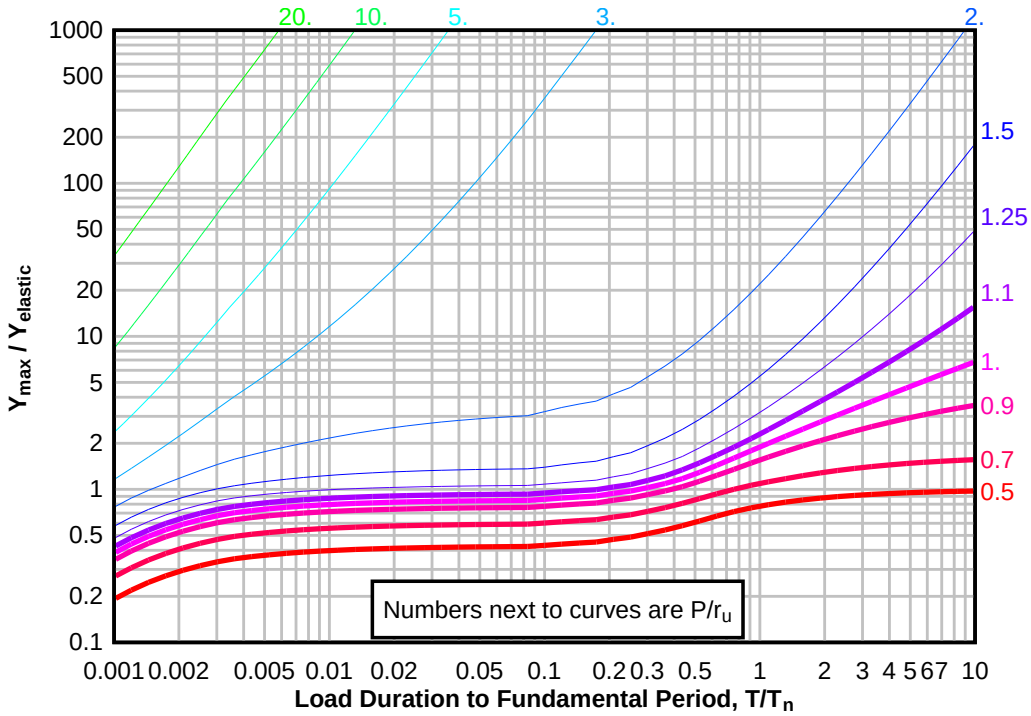


Figure 3-188(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.422, C2 = 300)

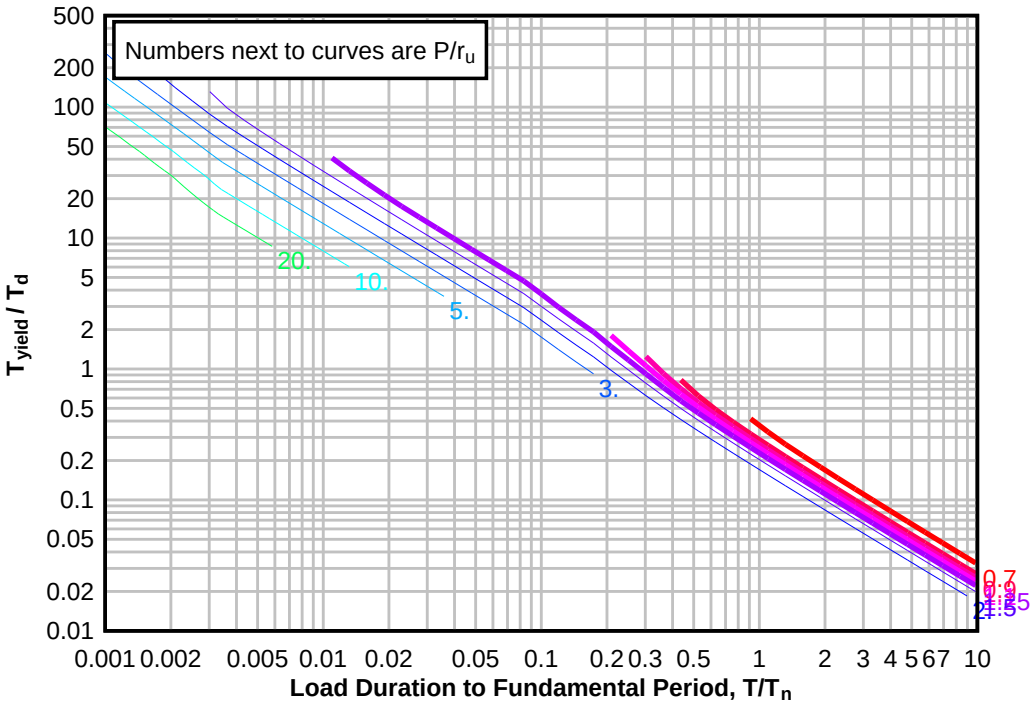


Figure 3-189(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.383, C_2 = 300)

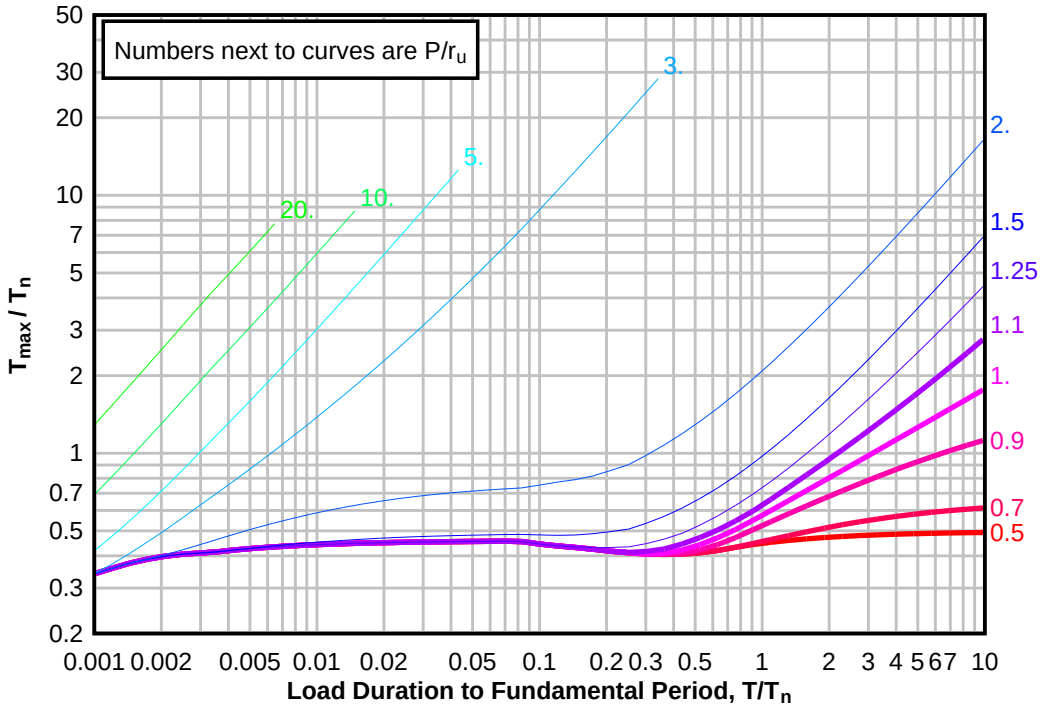


Figure 3-189(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.383, C2 = 300)

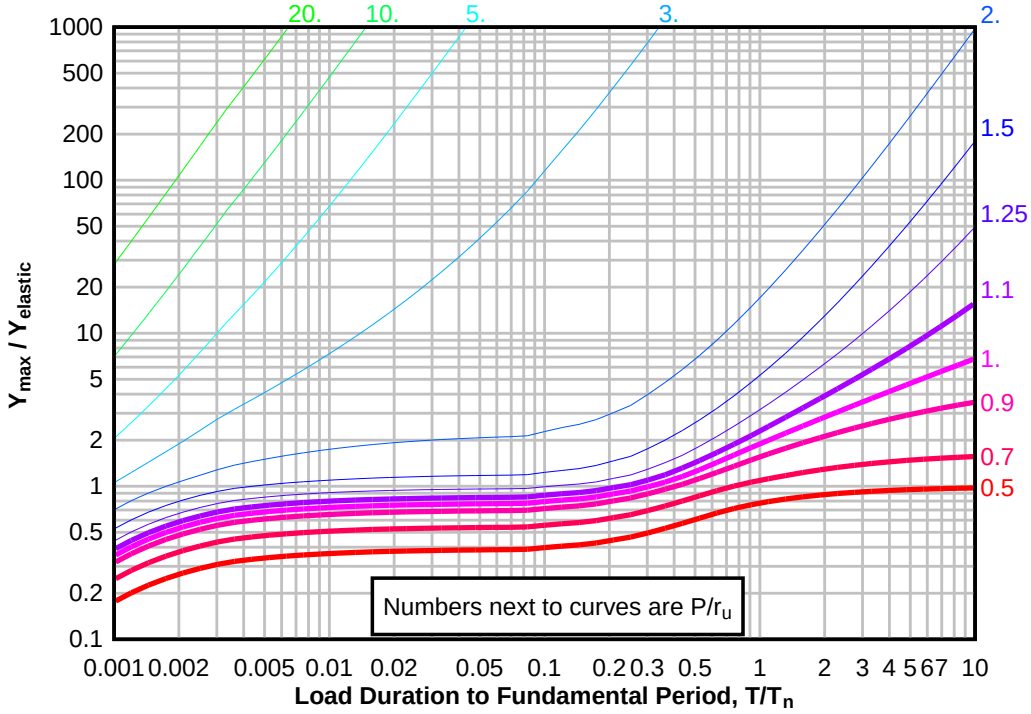


Figure 3-189(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.383, C2 = 300)

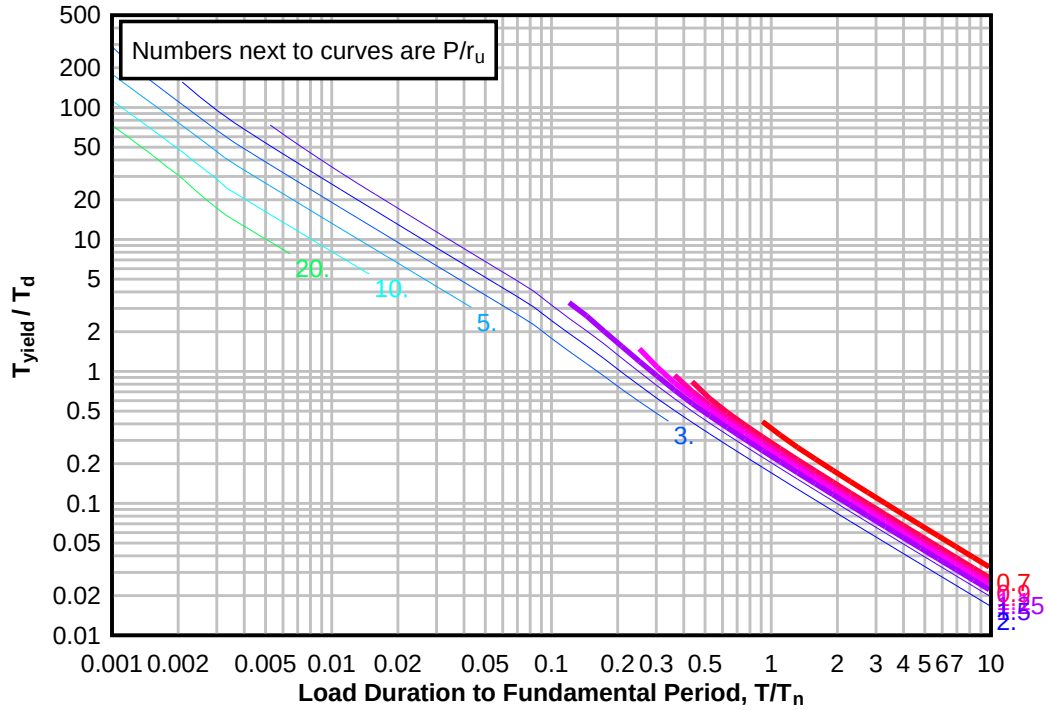


Figure 3-190(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.365, C_2 = 300)

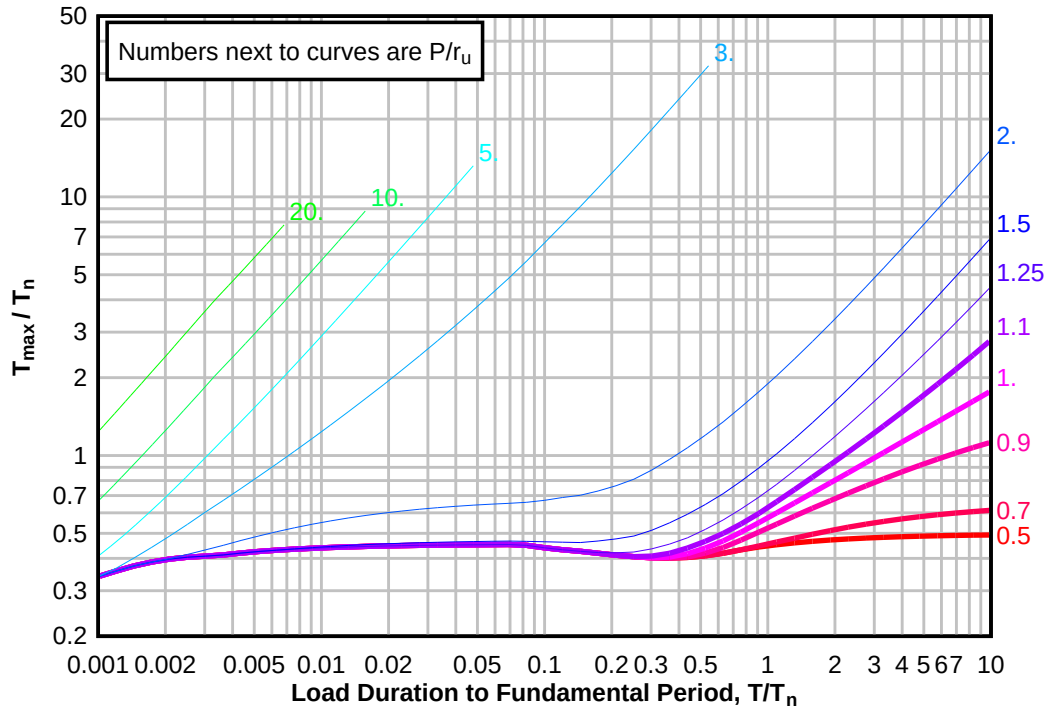


Figure 3-190(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.365, C2 = 300)

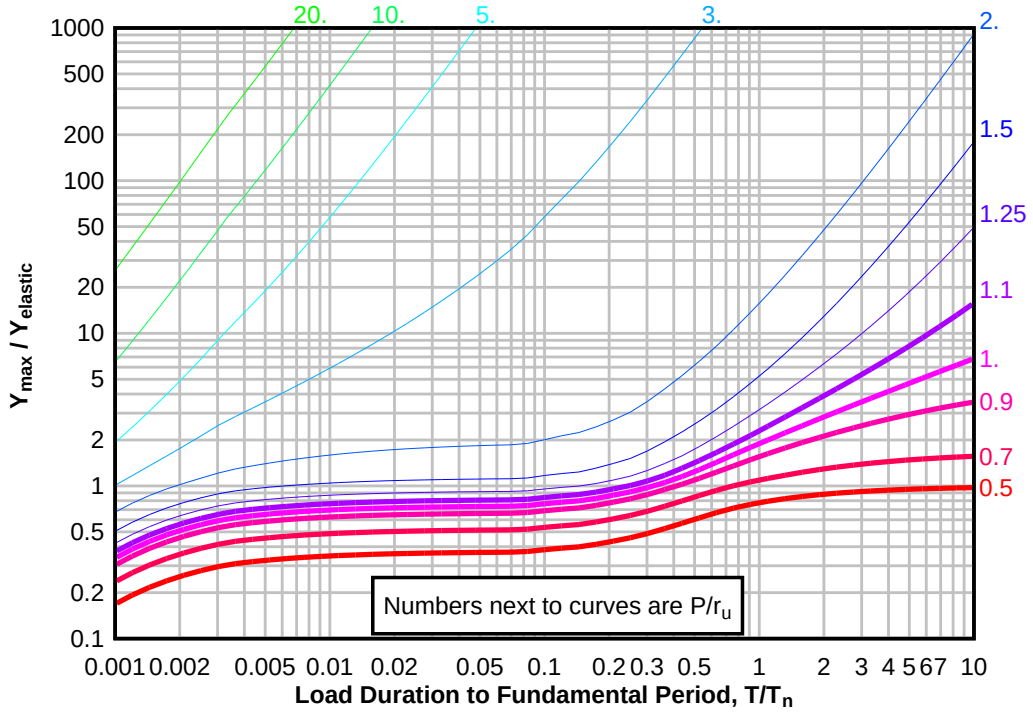


Figure 3-190(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.365, C2 = 300)

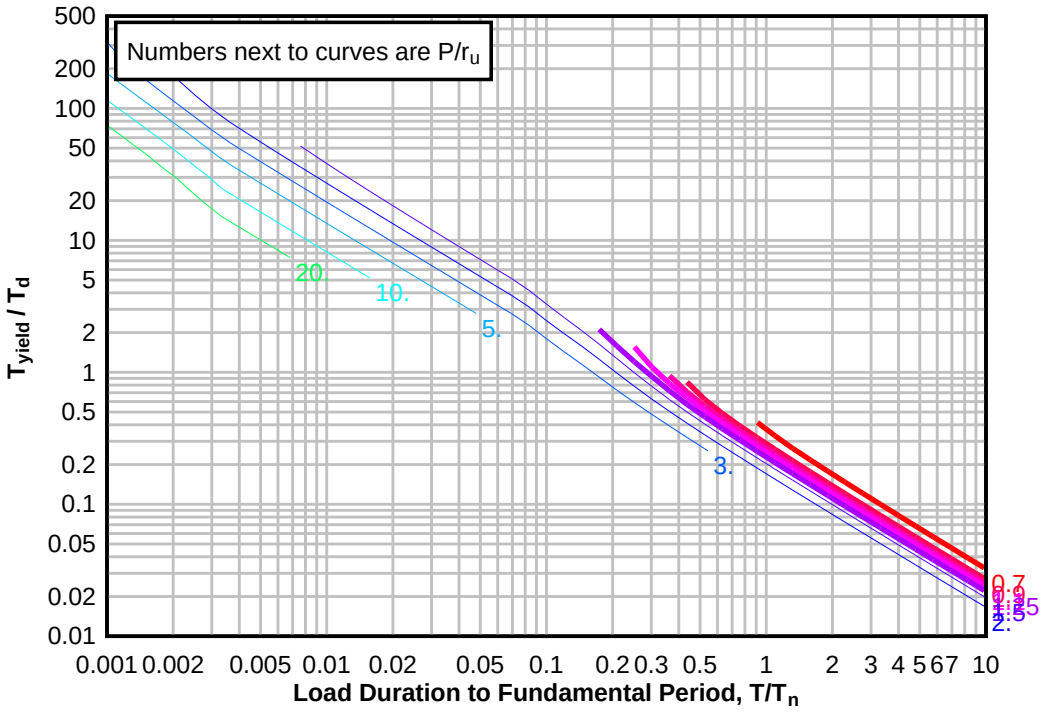


Figure 3-191(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.348, C_2 = 300)

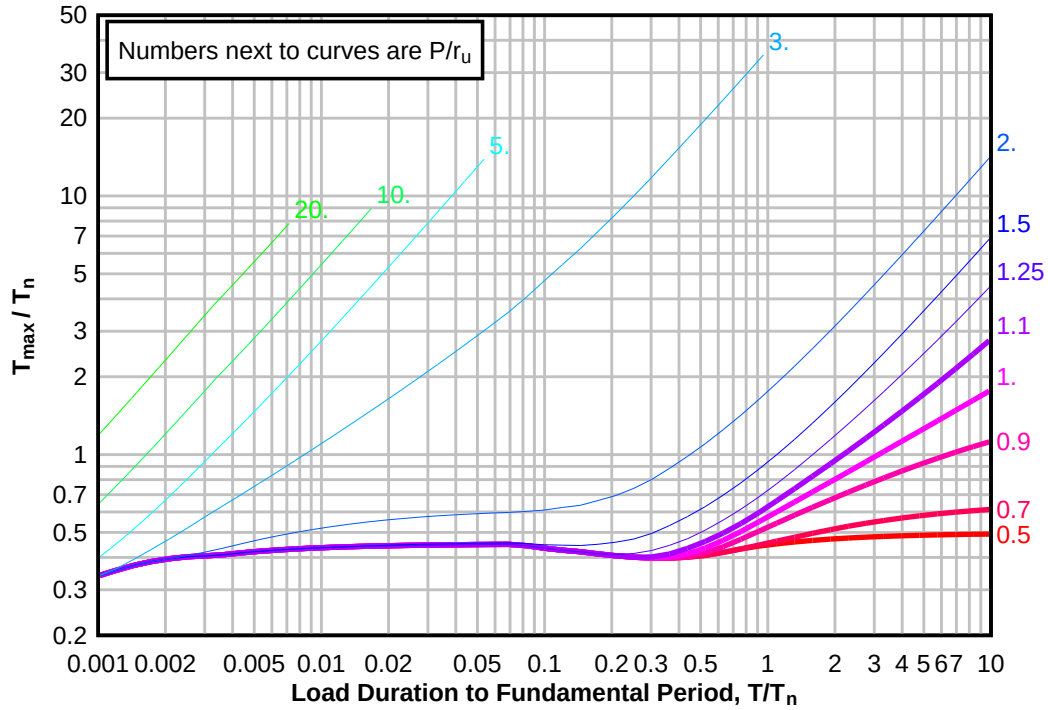


Figure 3-191(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.348, C2 = 300)

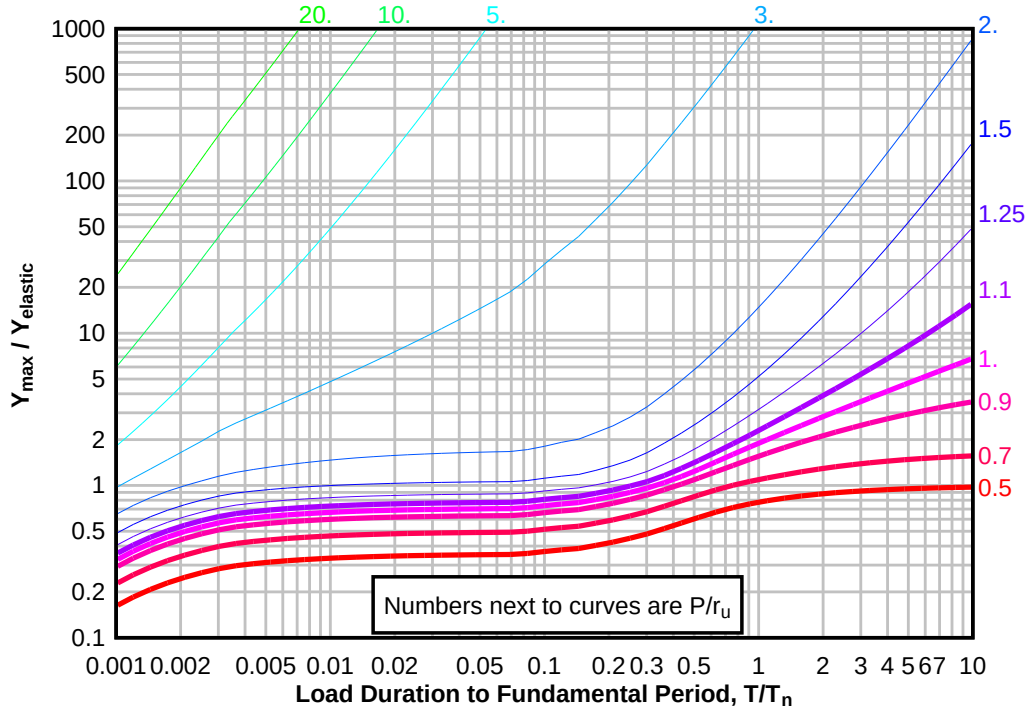


Figure 3-191(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.348, C2 = 300)

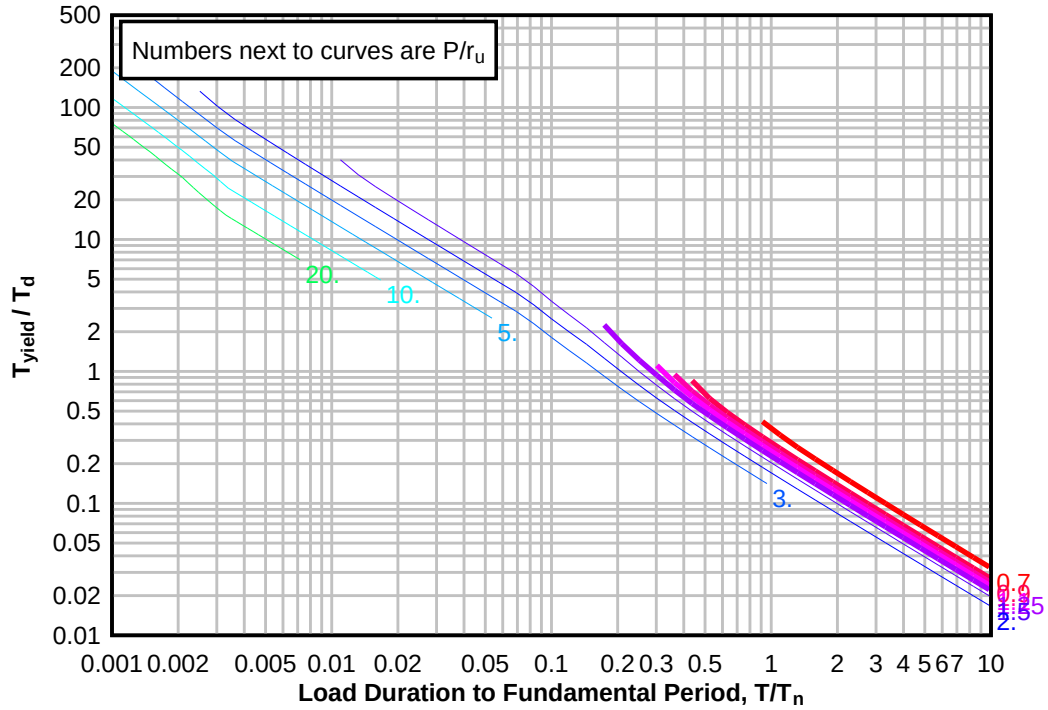


Figure 3-192(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.316, C_2 = 300)

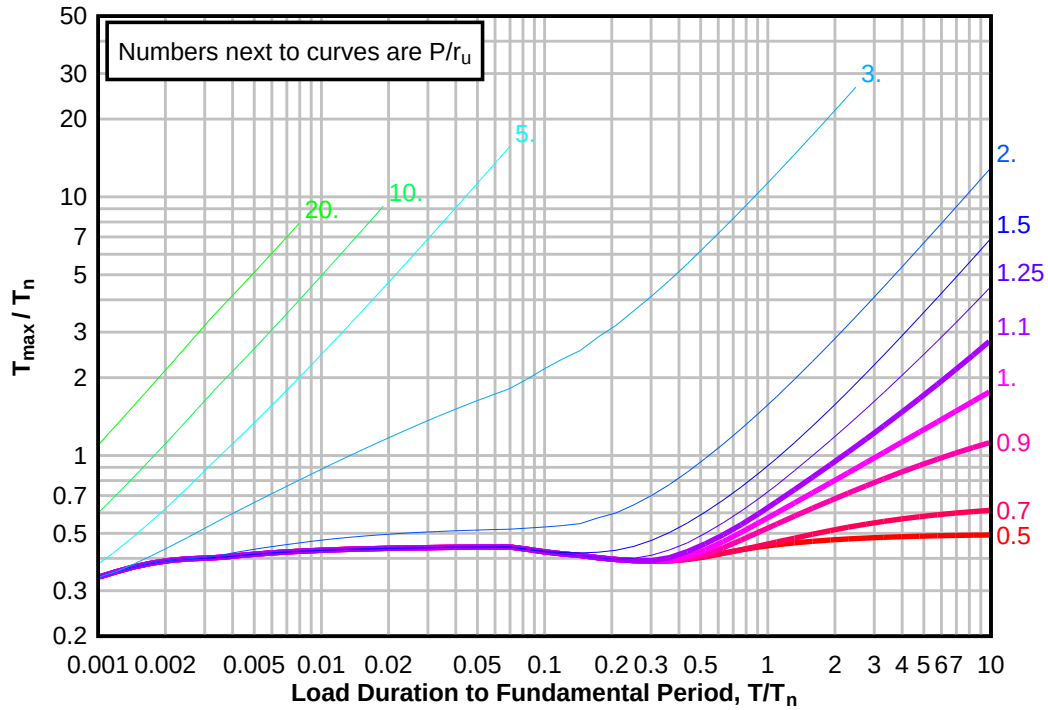


Figure 3-192(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.316, C2 = 300)

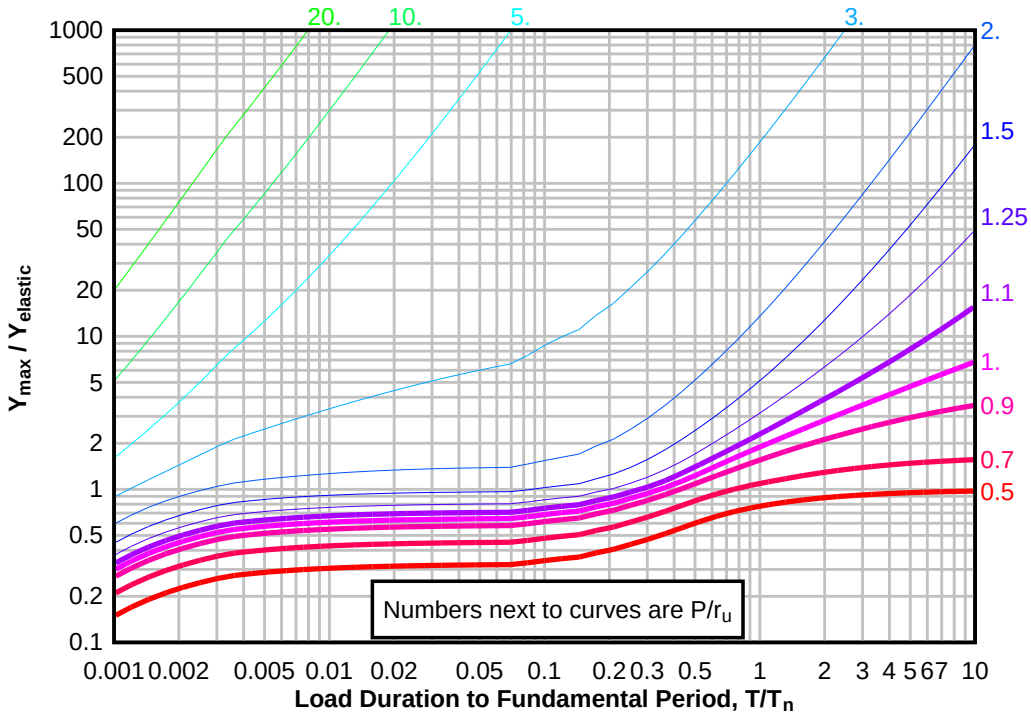


Figure 3-192(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.316, C2 = 300)

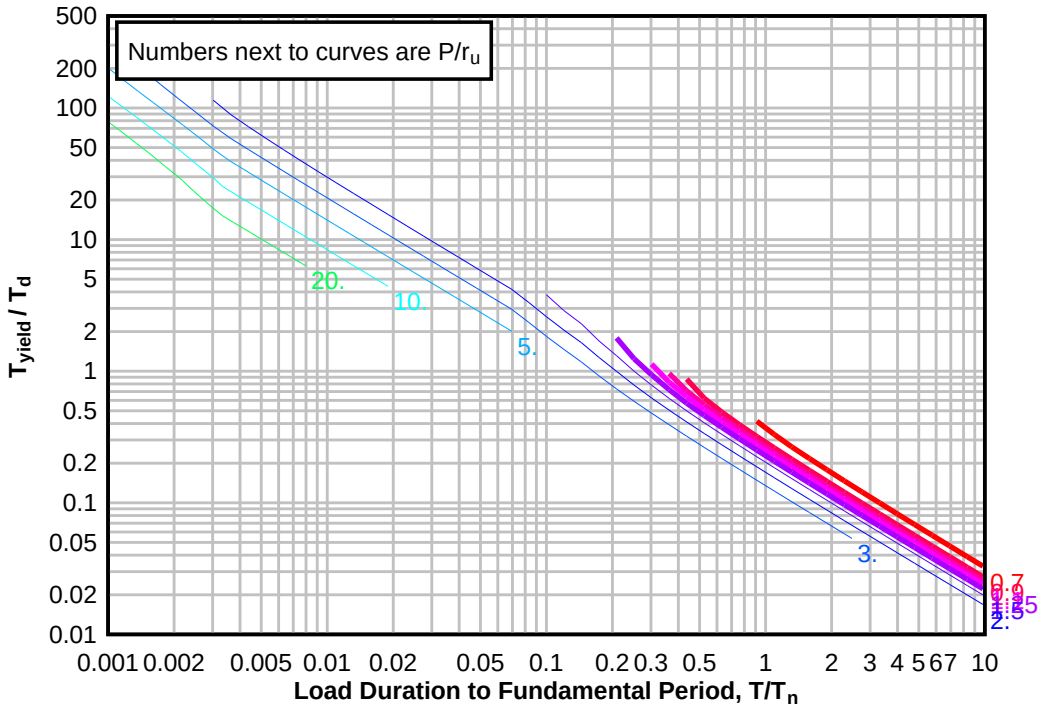


Figure 3-193(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.287, C_2 = 300)

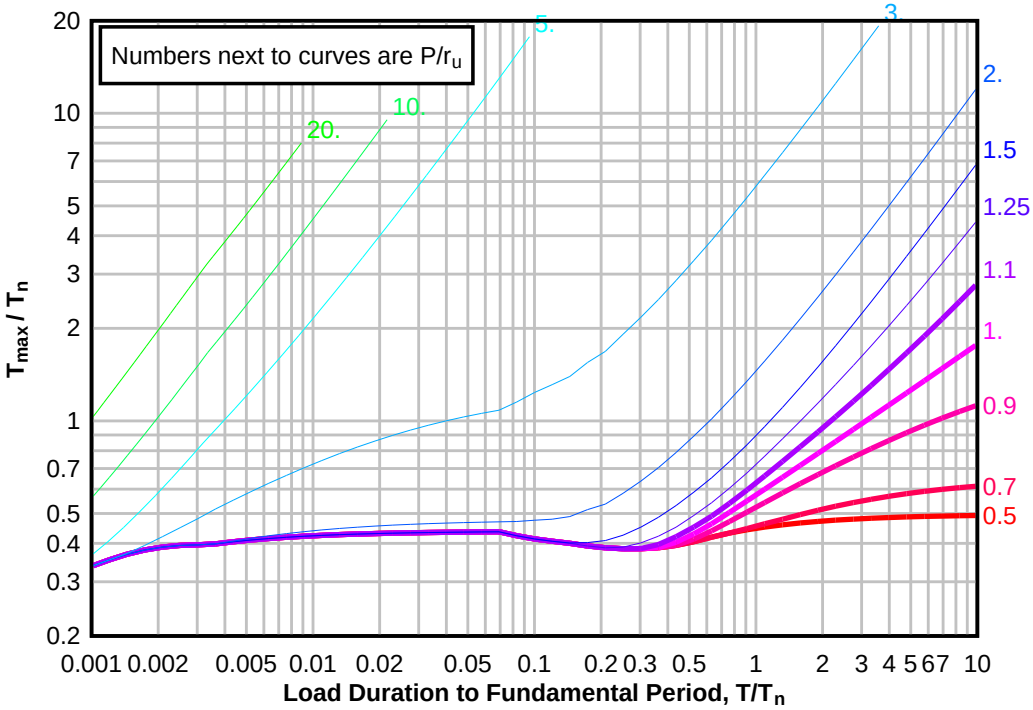


Figure 3-193(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.287, C2 = 300)

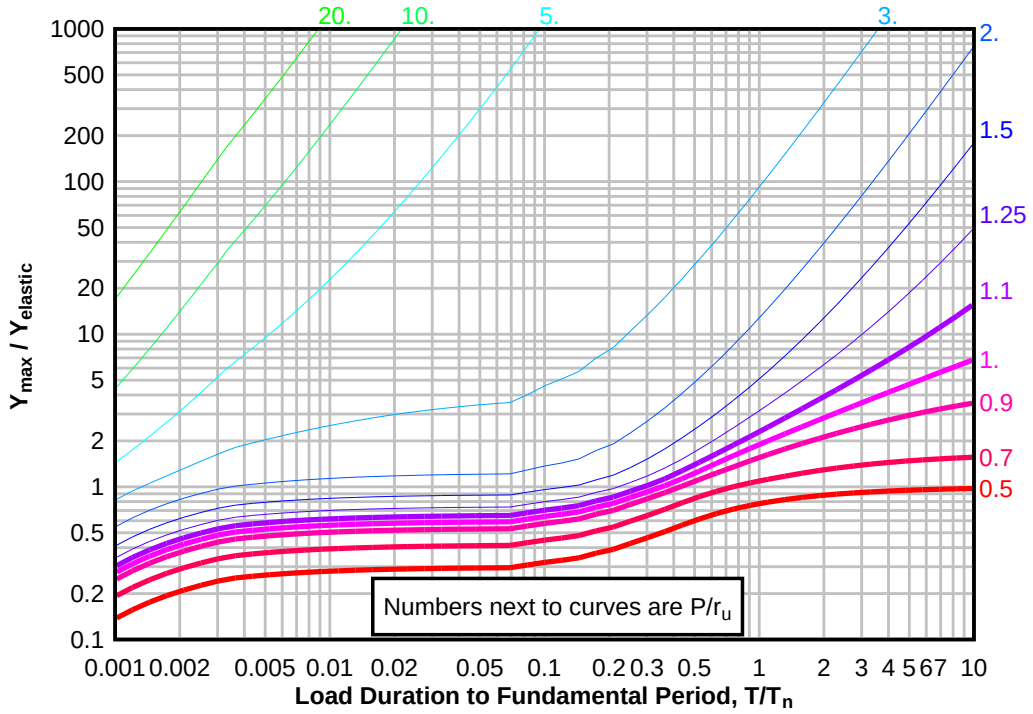


Figure 3-193(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.287, C2 = 300)

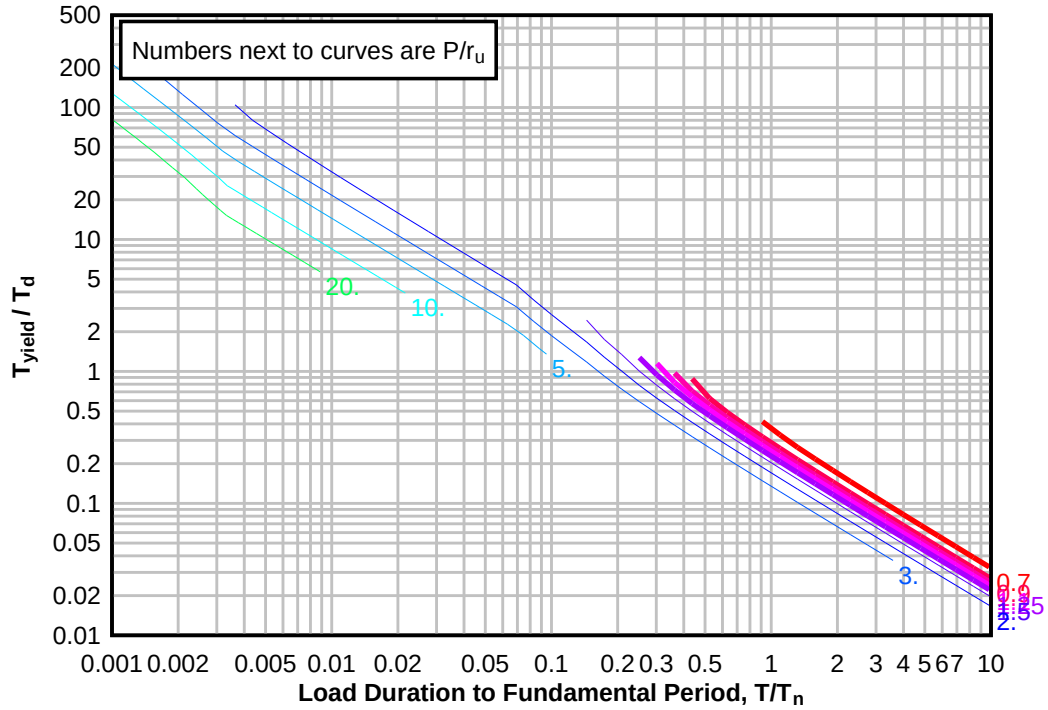


Figure 3-194(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.274, C_2 = 300)

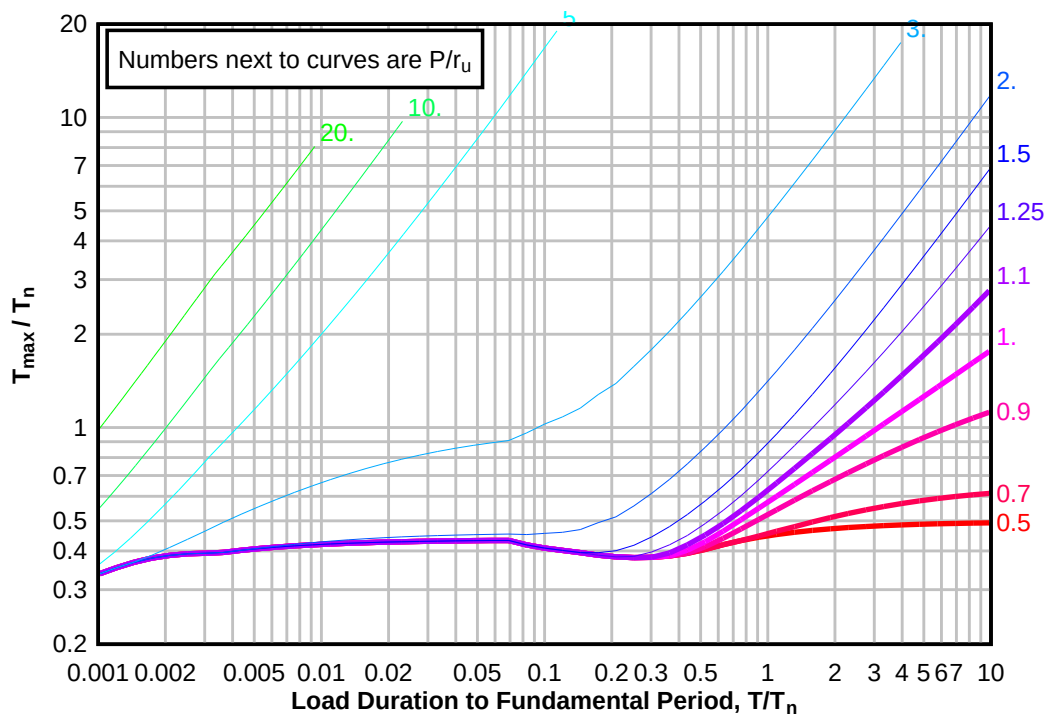


Figure 3-194(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.274, C2 = 300)

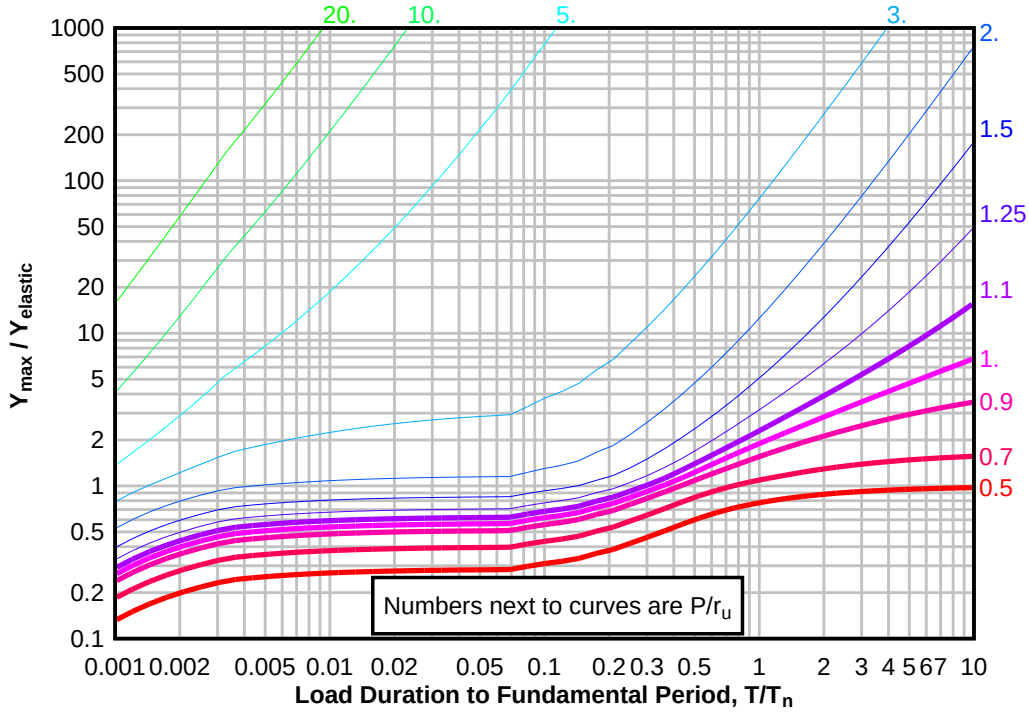


Figure 3-194(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.274, C2 = 300)

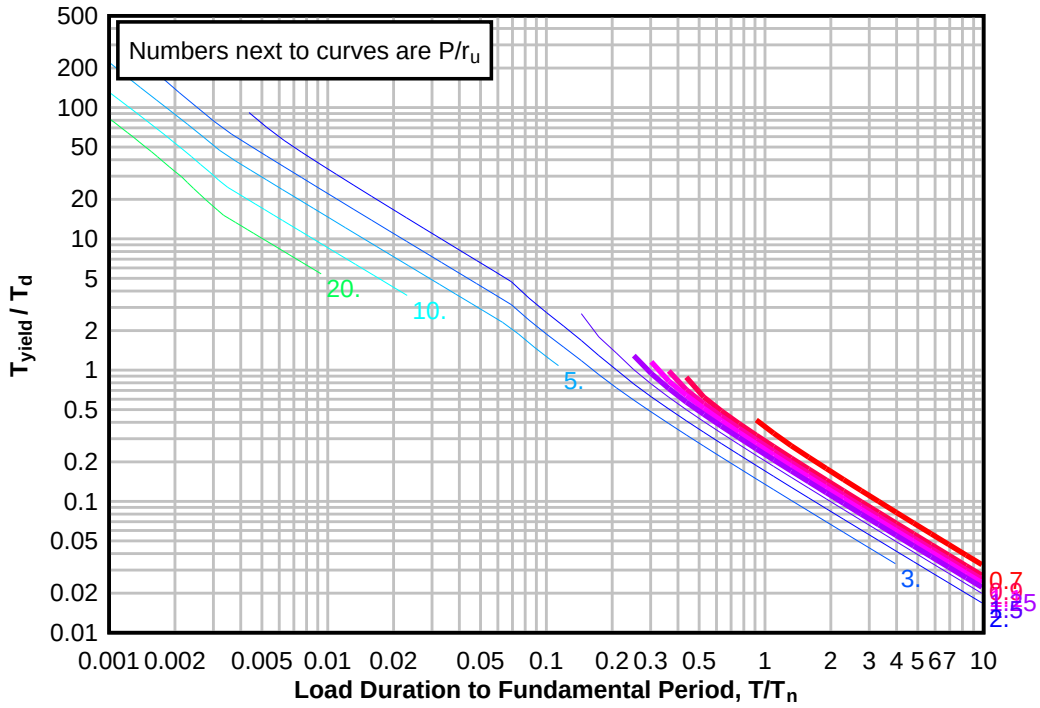


Figure 3-195(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.261, C_2 = 300)

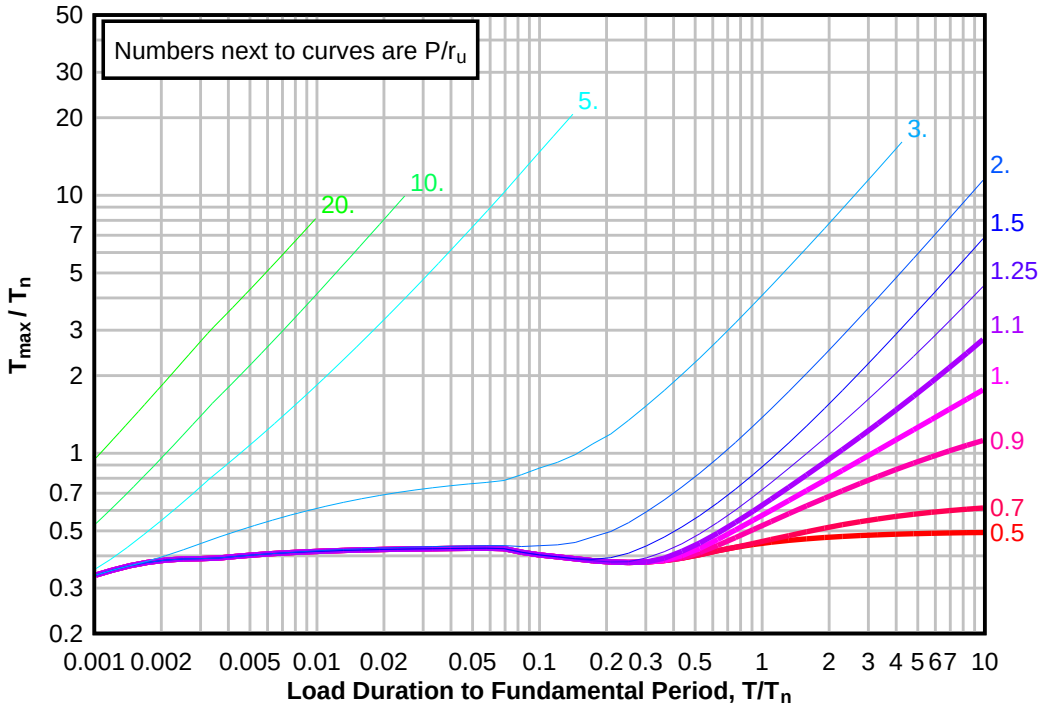


Figure 3-195(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.261, C2 = 300)

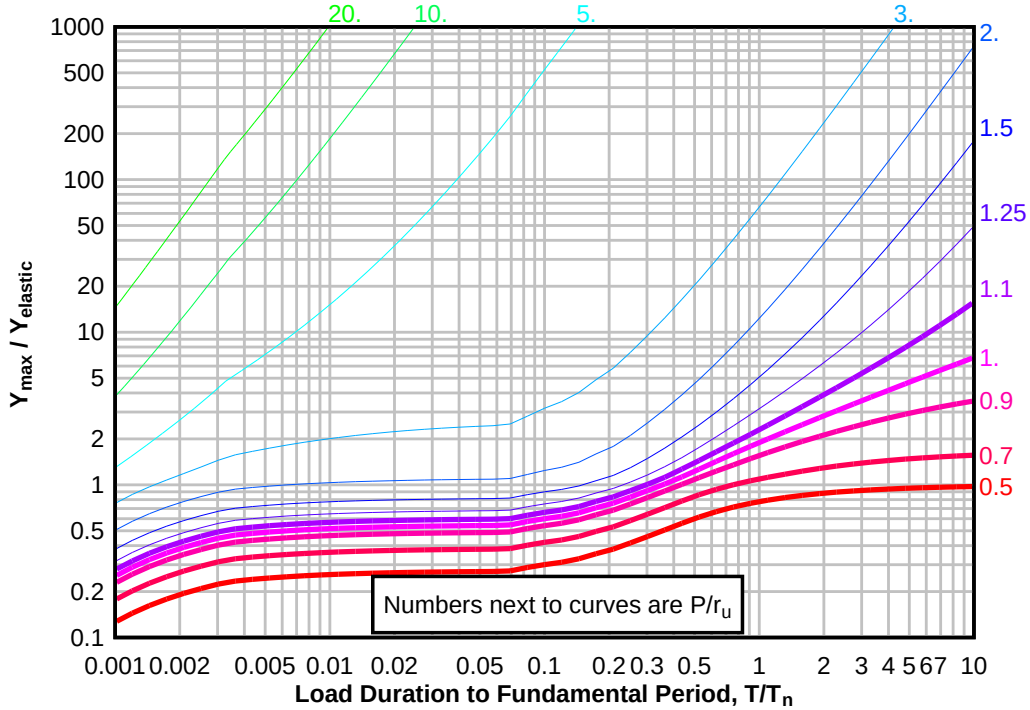


Figure 3-195(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.261, C2 = 300)

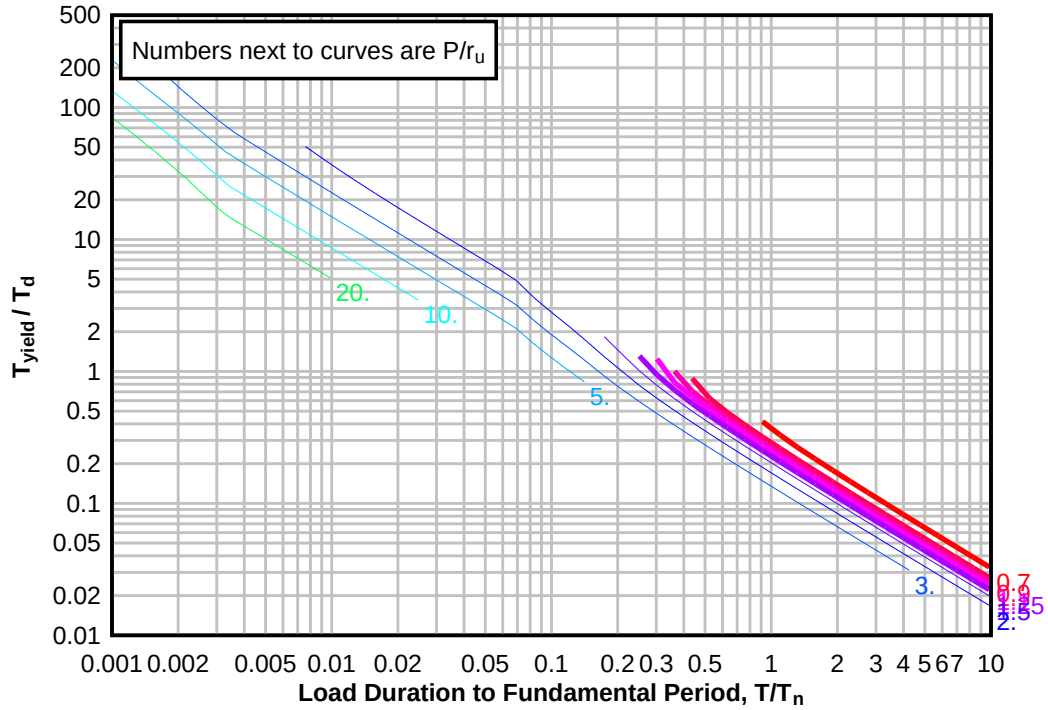


Figure 3-196(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.237, C_2 = 300)

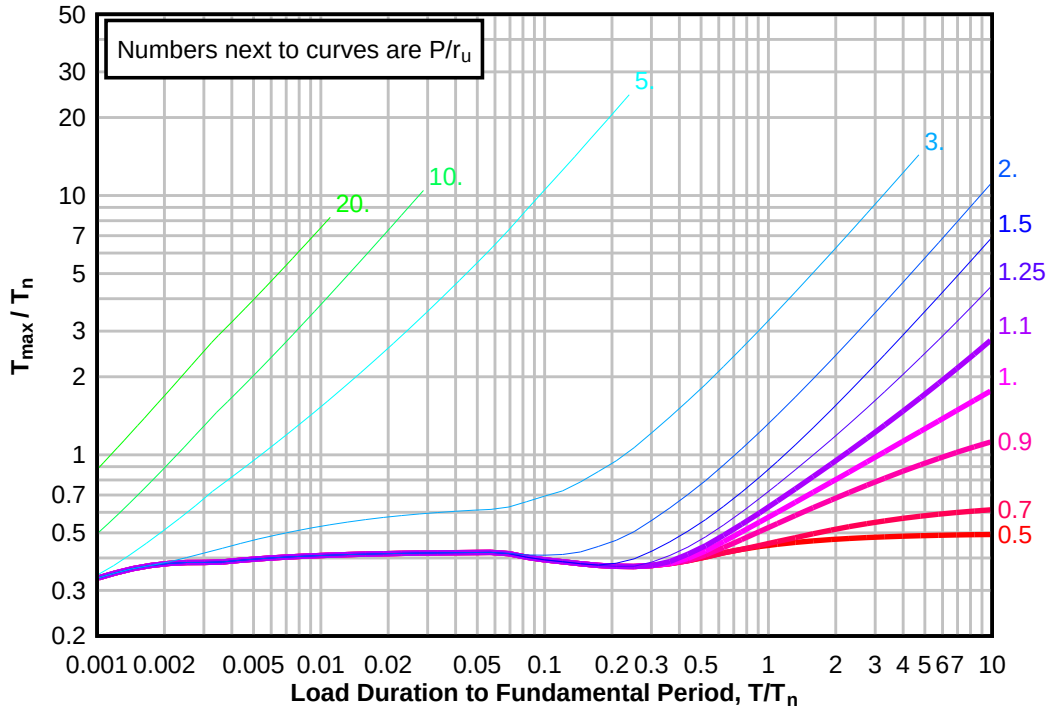


Figure 3-196(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.237, C2 = 300)

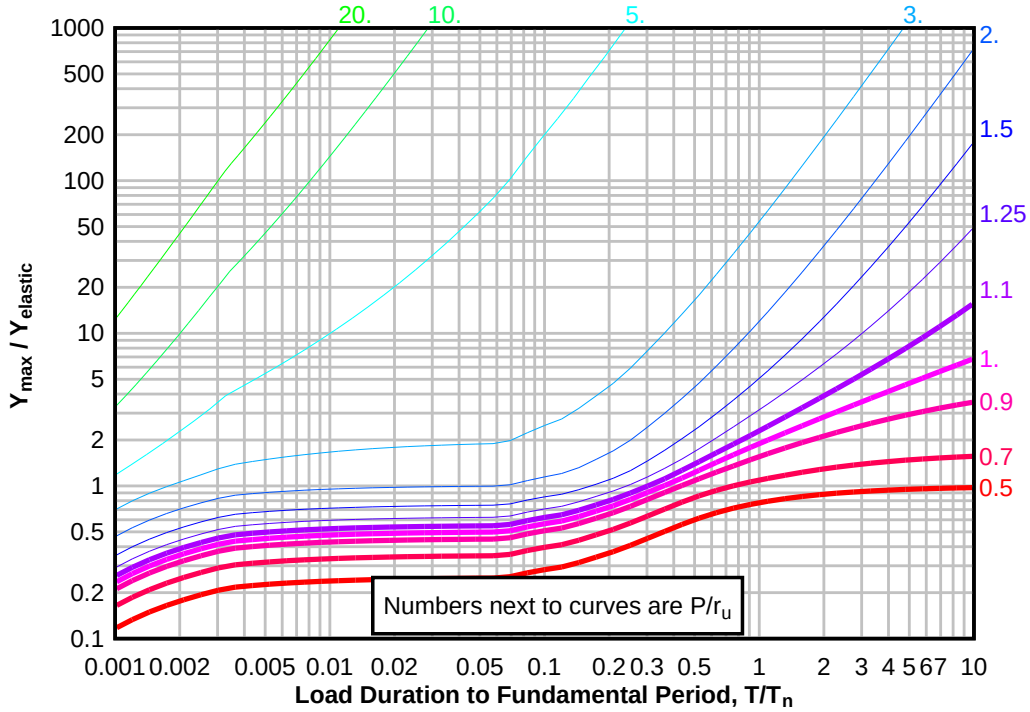


Figure 3-196(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.237, C2 = 300)

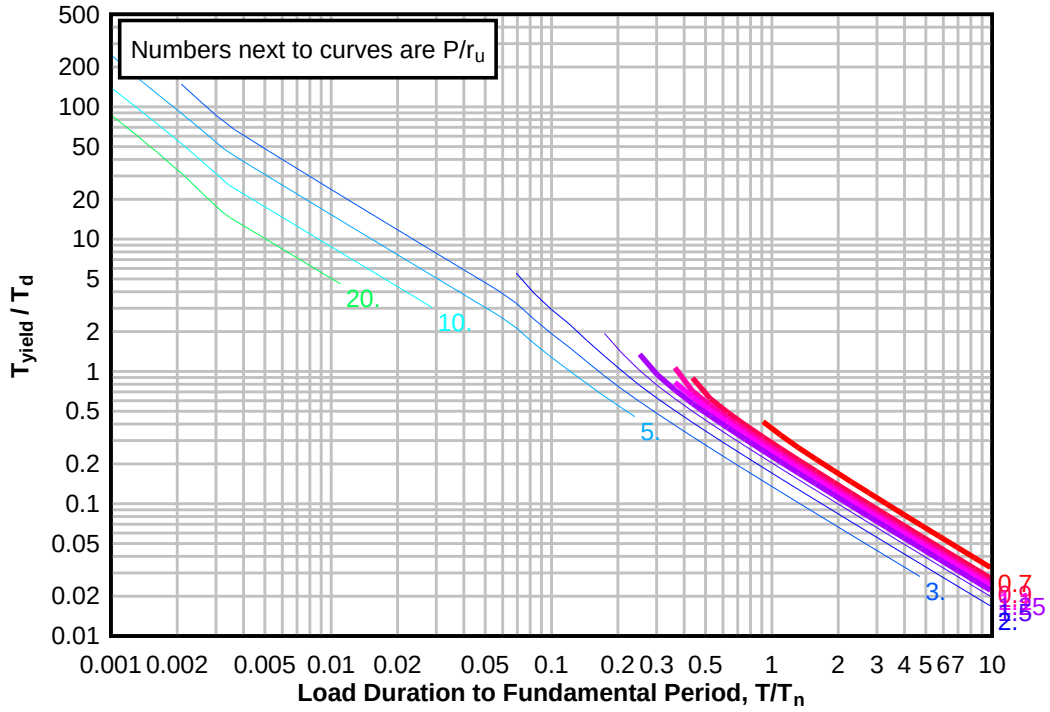


Figure 3-197(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangle Pulse (C_1 = 0.215, C_2 = 300)

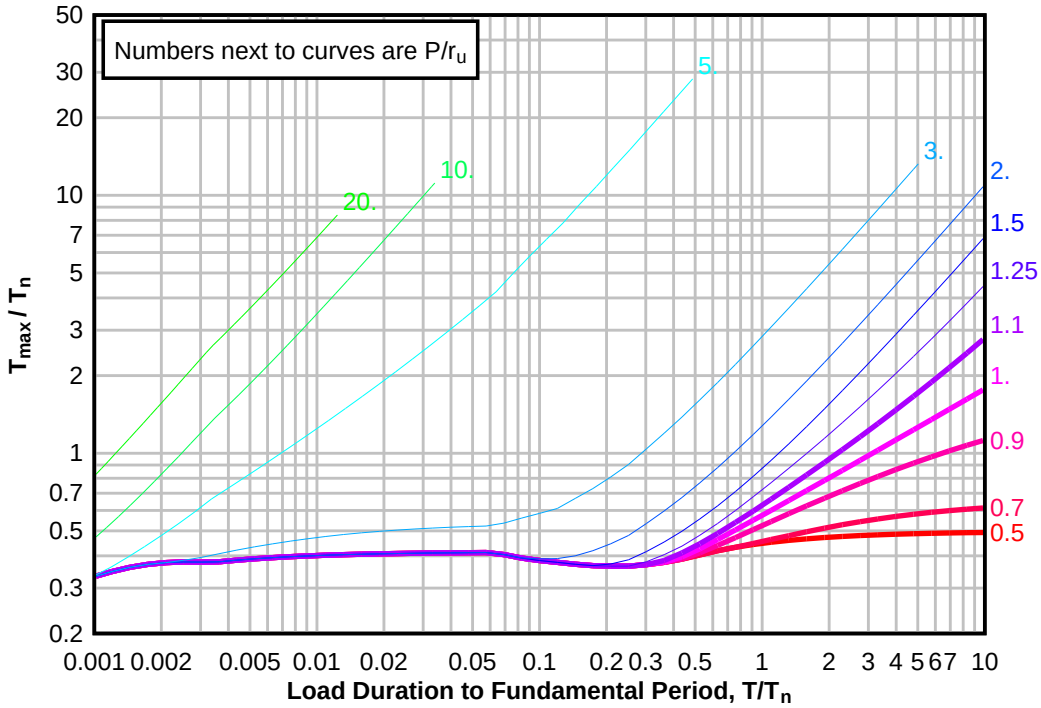


Figure 3-197(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangle Pulse (C1 = 0.215, C2 = 300)

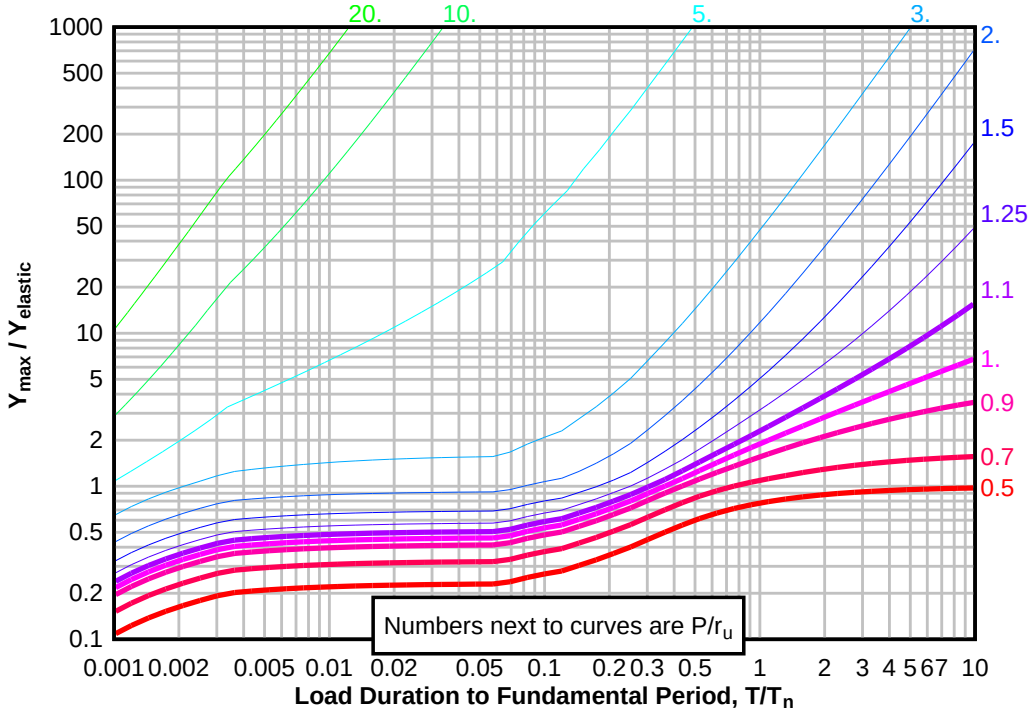


Figure 3-197(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangle Pulse (C1 = 0.215, C2 = 300)

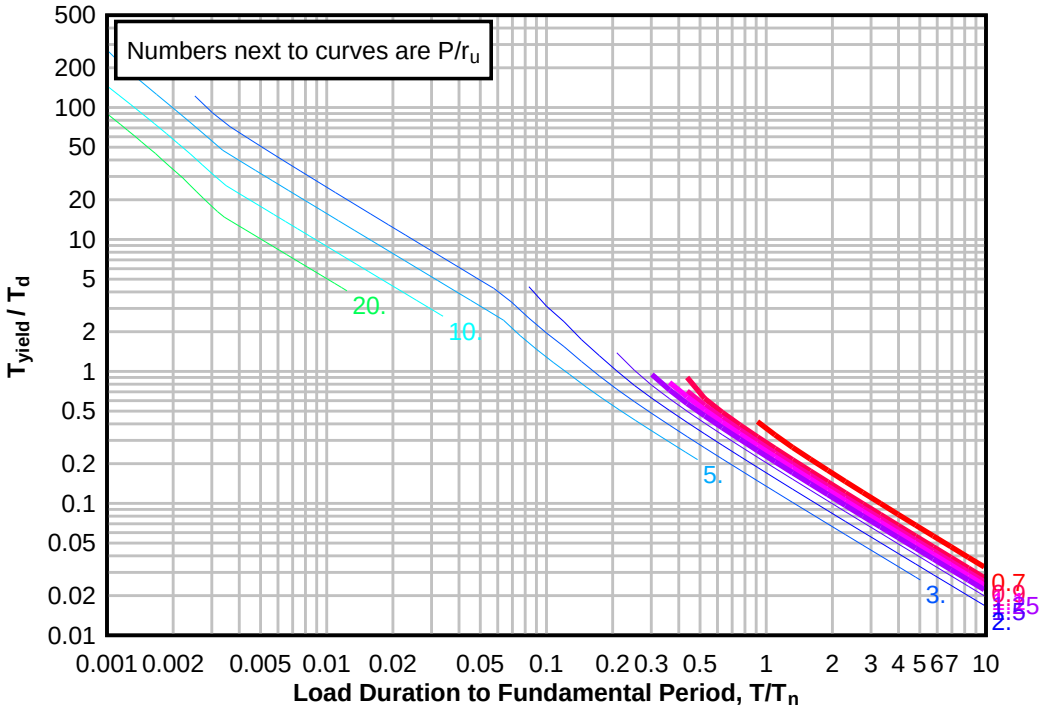


Figure 3-198(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.198, C_2 = 300)

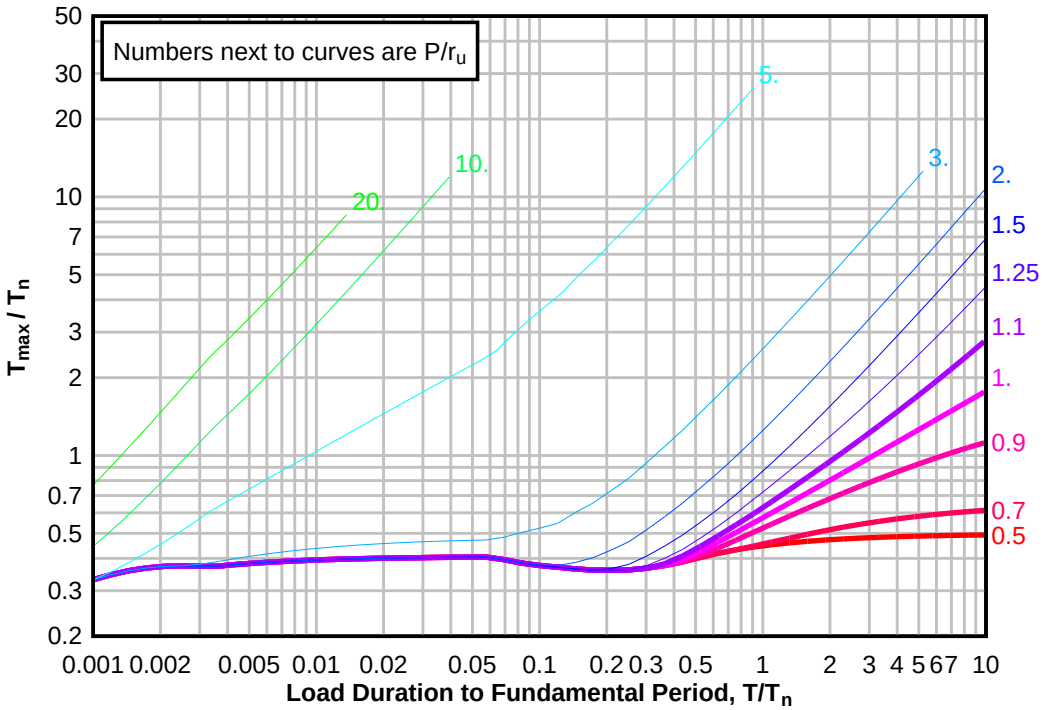


Figure 3-198(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.198, C2 = 300)

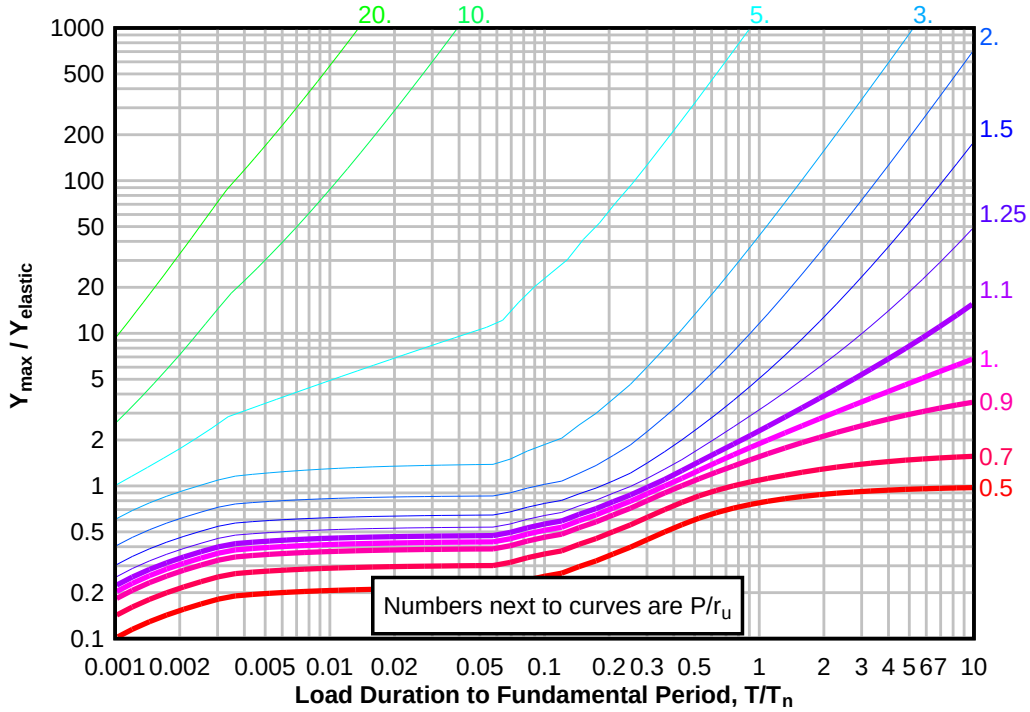


Figure 3-198(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.198, C2 = 300)

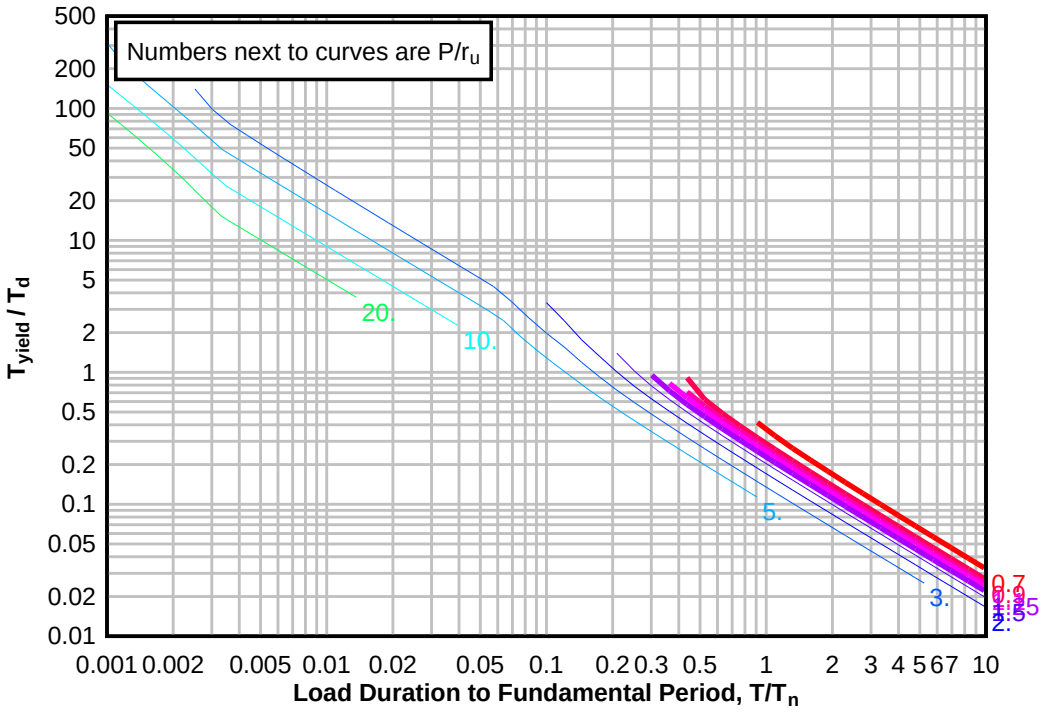


Figure 3-199(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.178, C_2 = 300)

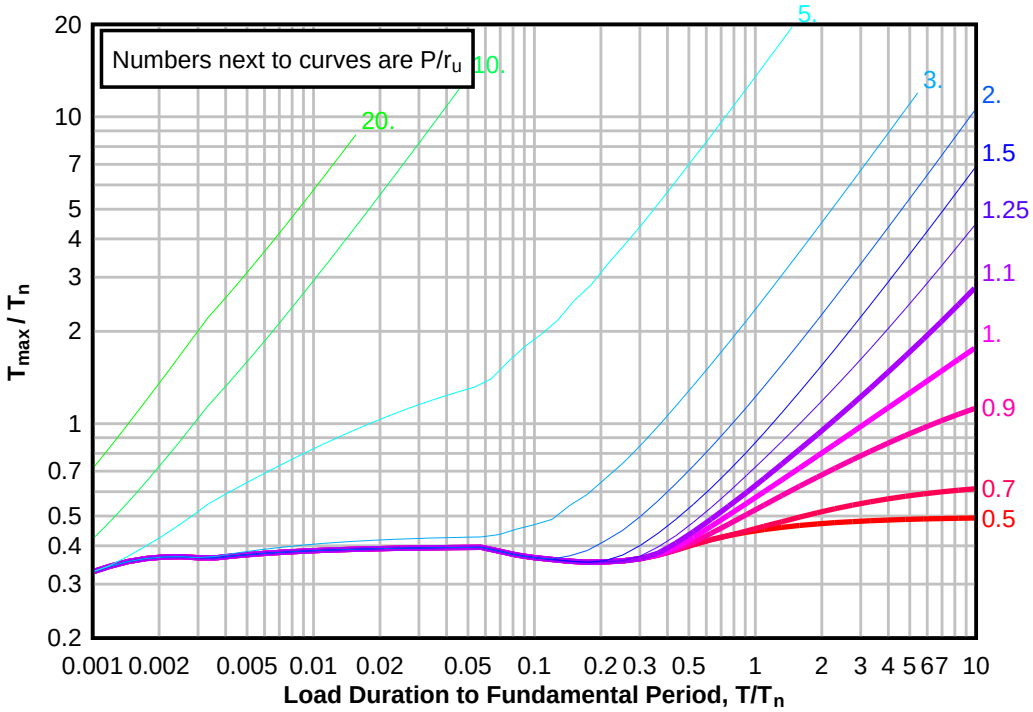


Figure 3-199(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.178, C2 = 300)

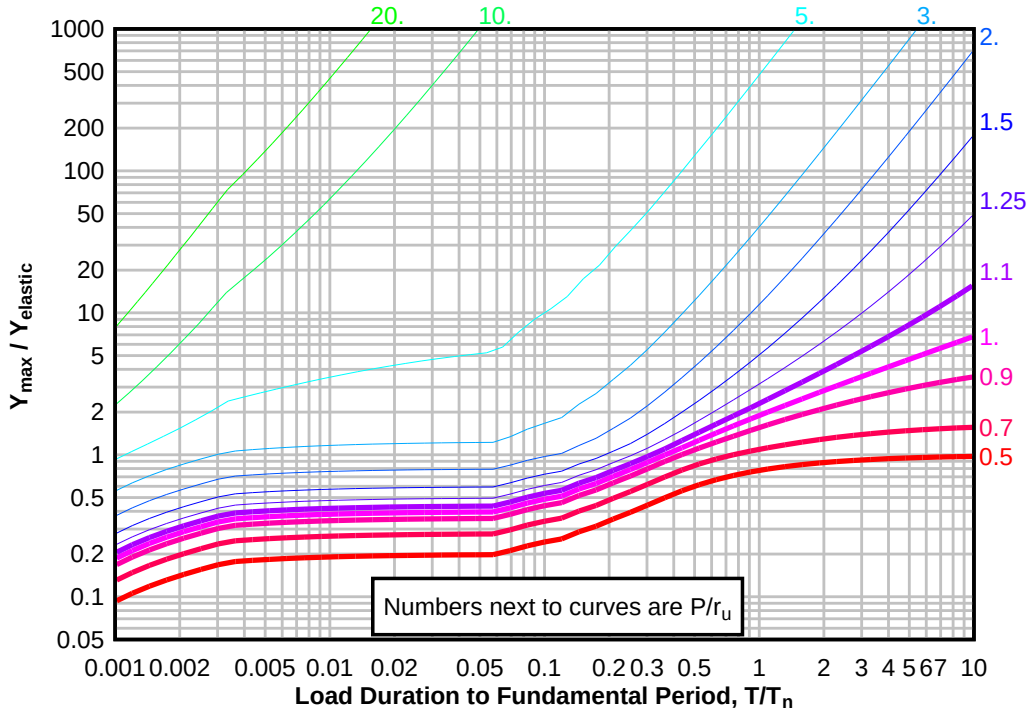


Figure 3-199(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.178, C2 = 300)

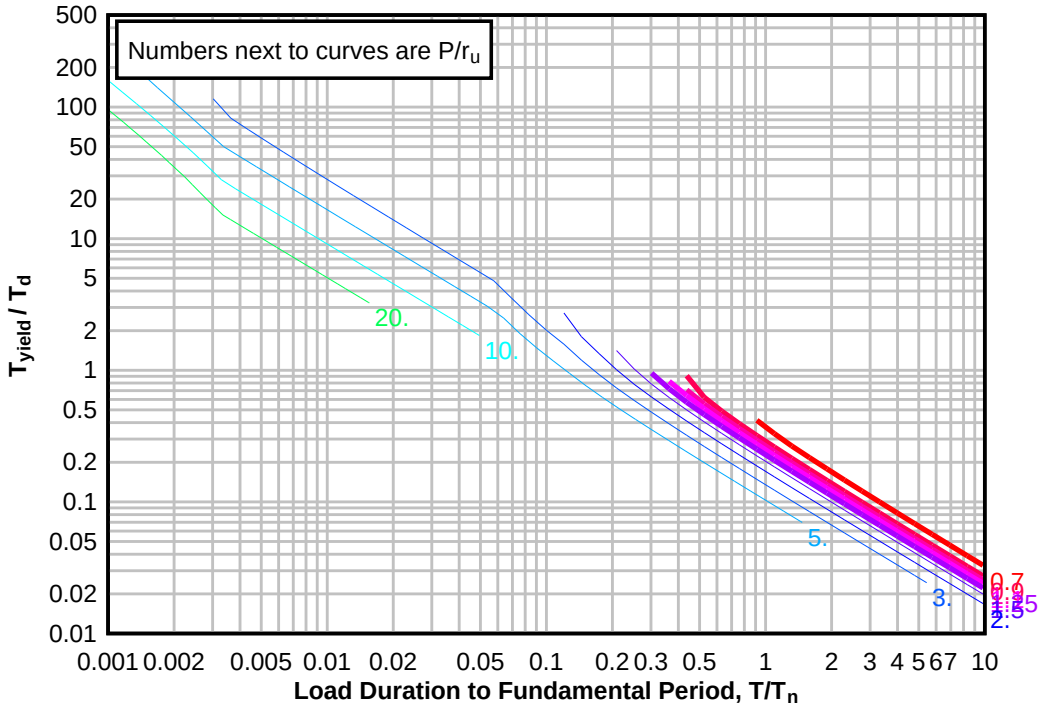


Figure 3-200(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.162, C_2 = 300)

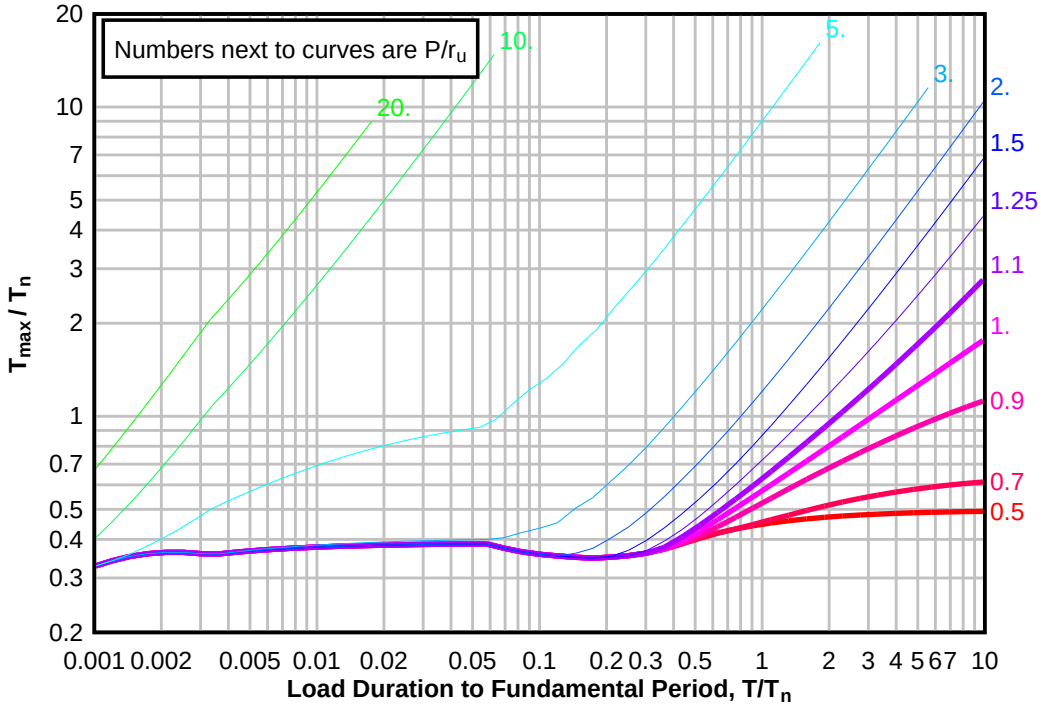


Figure 3-200(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.162, C2 = 300)

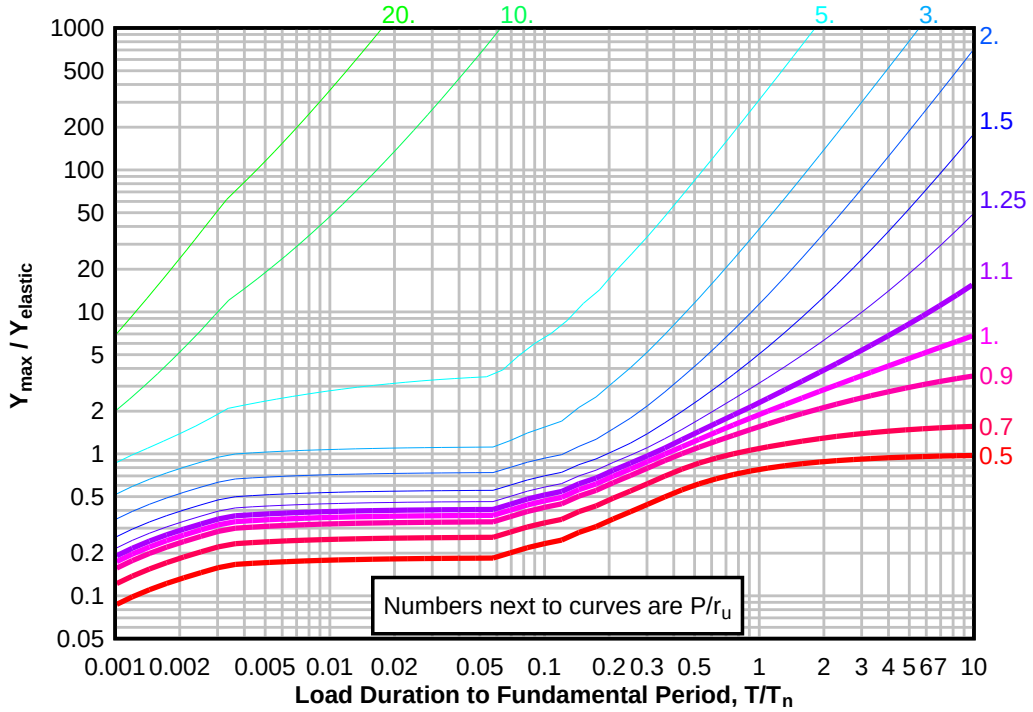


Figure 3-200(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.162, C2 = 300)

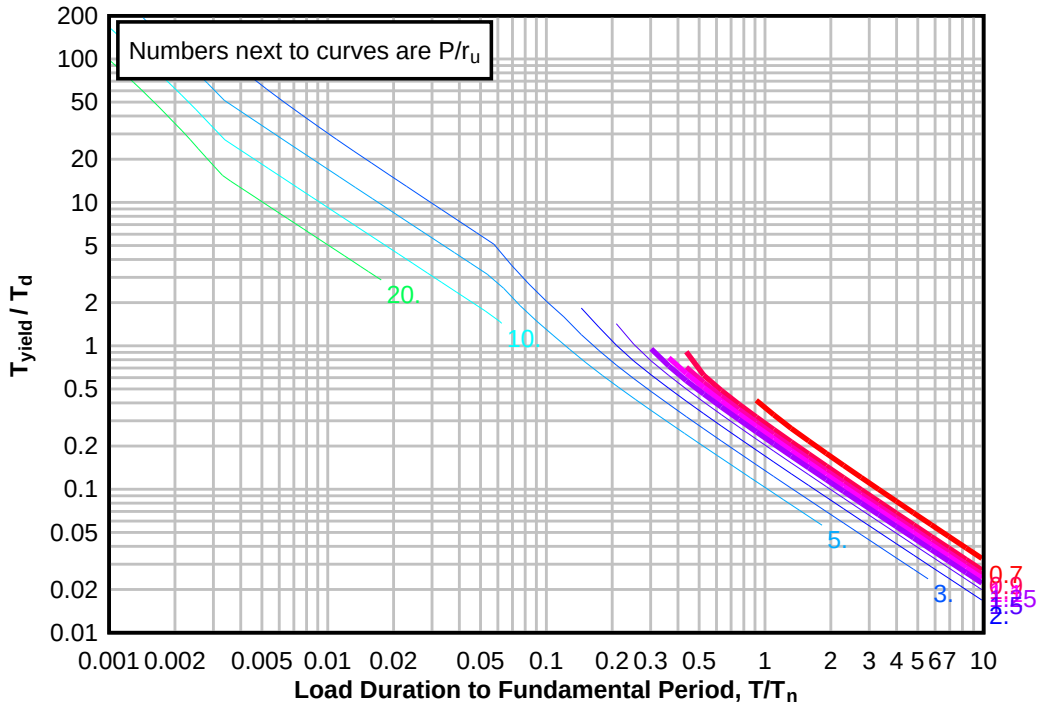


Figure 3-201(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.147, C_2 = 300)

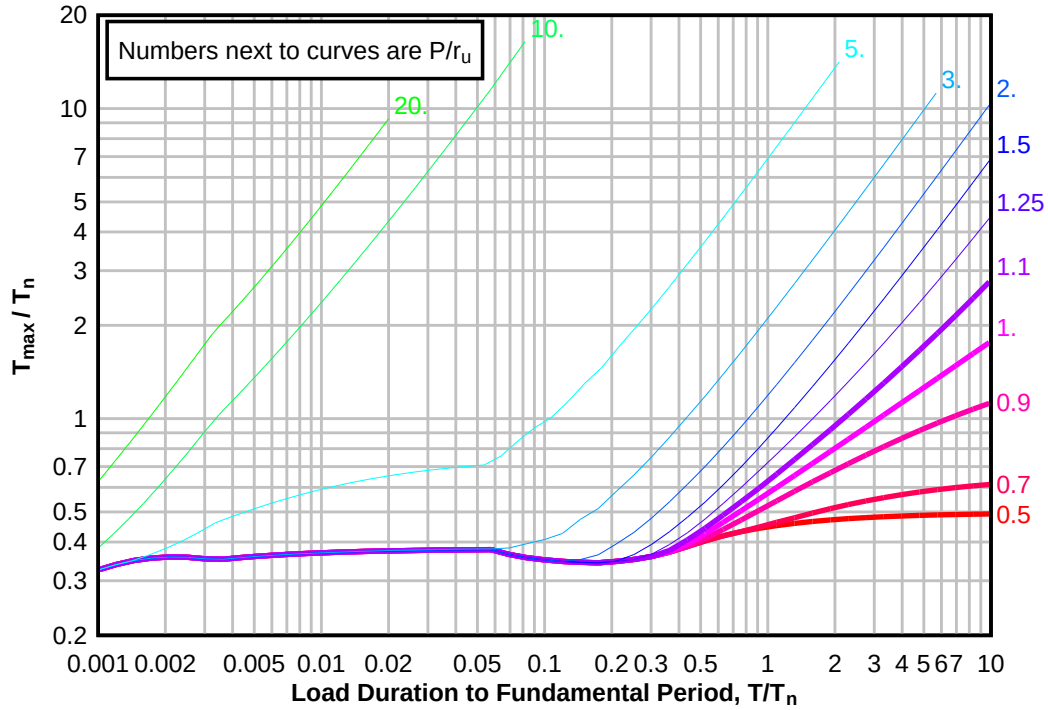


Figure 3-201(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.147, C2 = 300)

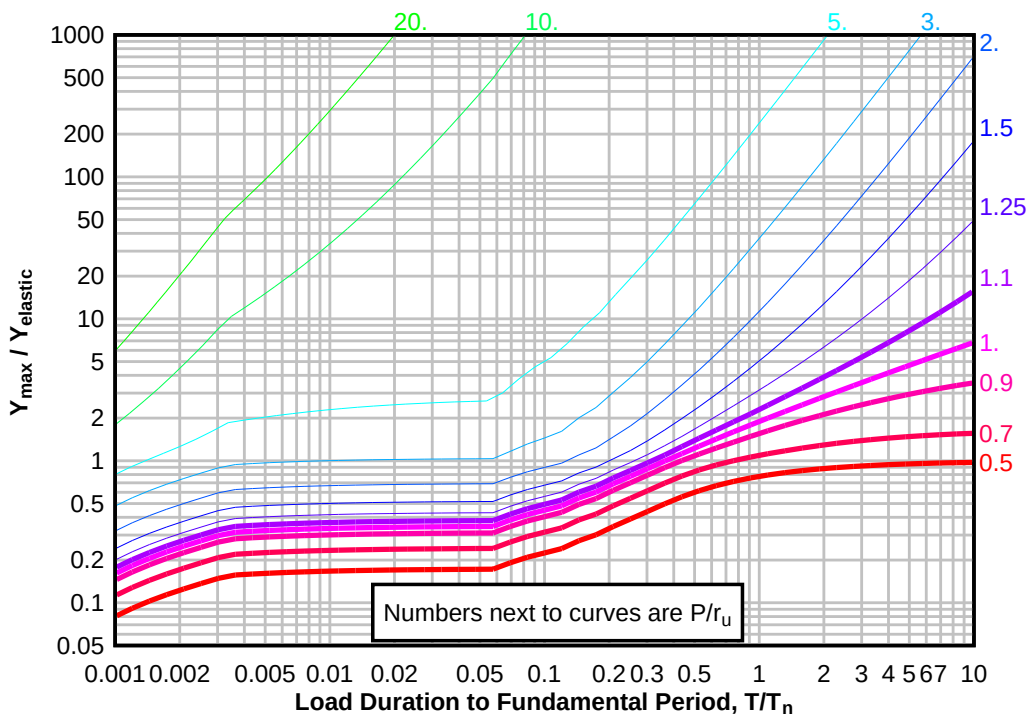


Figure 3-201(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.147, C2 = 300)

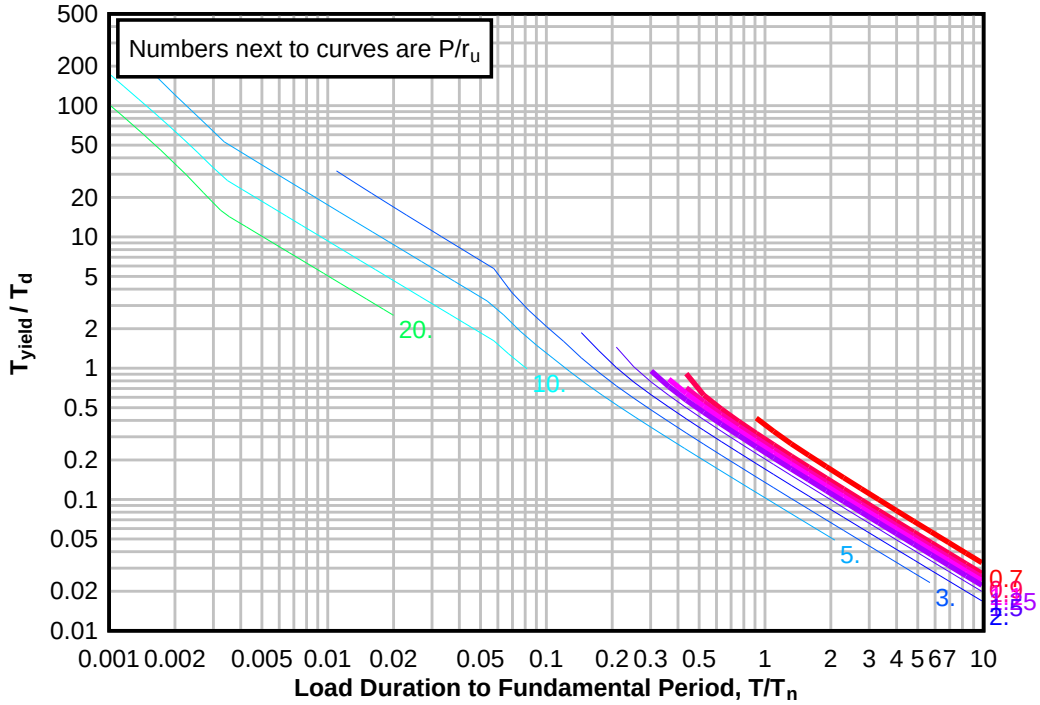


Figure 3-202(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.133, C_2 = 300)

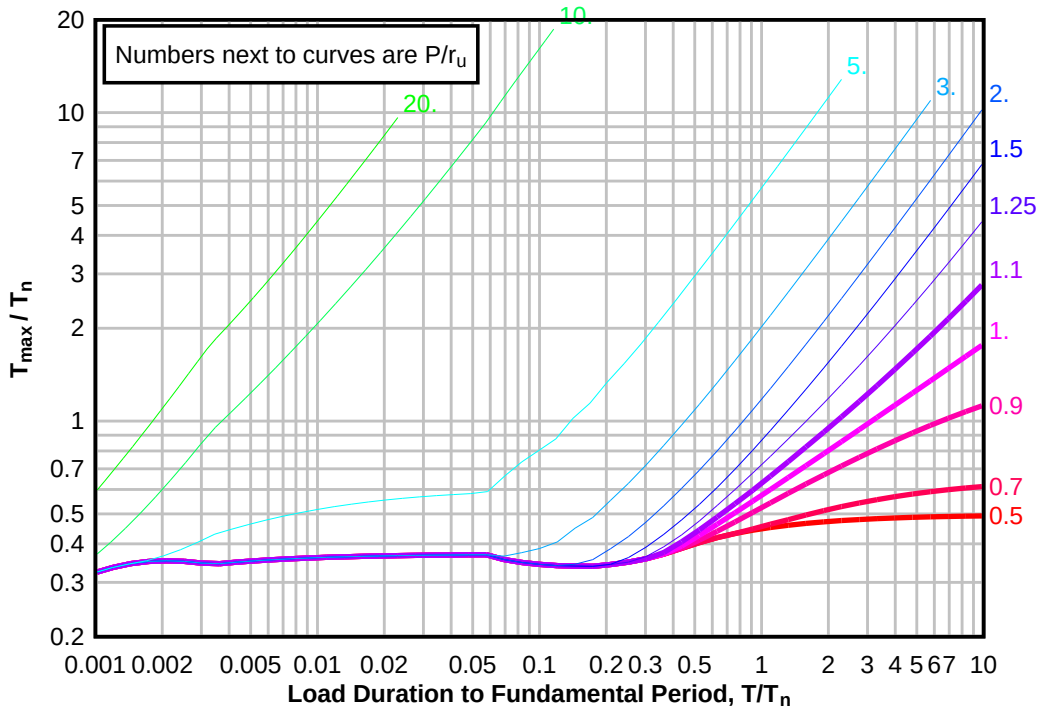


Figure 3-202(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.133, C2 = 300)

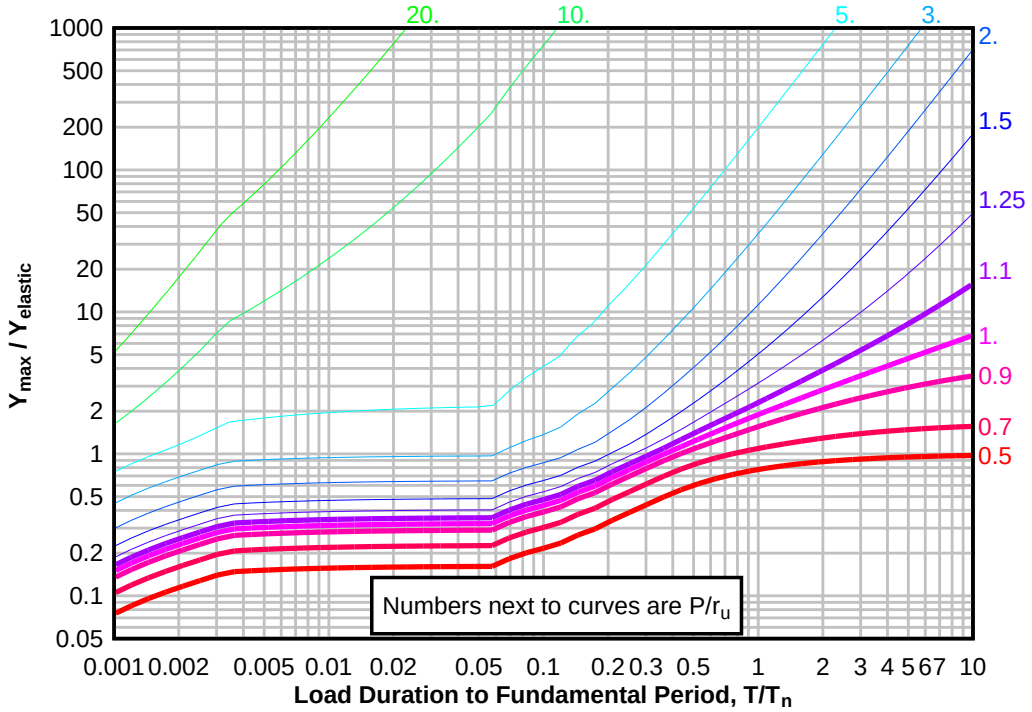


Figure 3-202(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.133, C2 = 300)

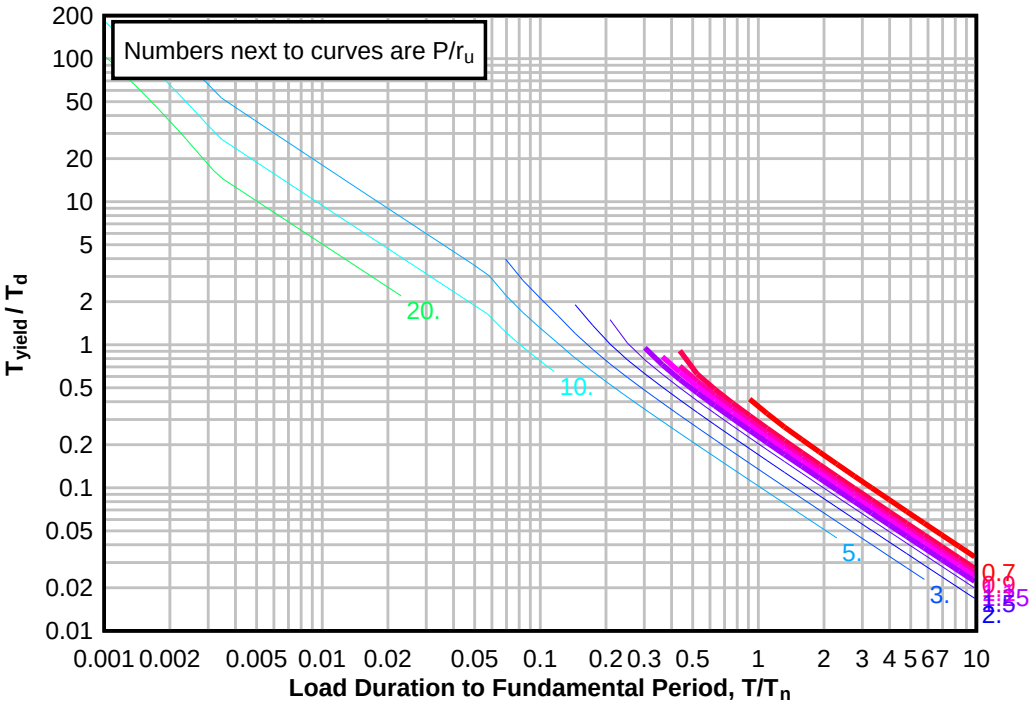


Figure 3-203(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.121, C_2 = 300)

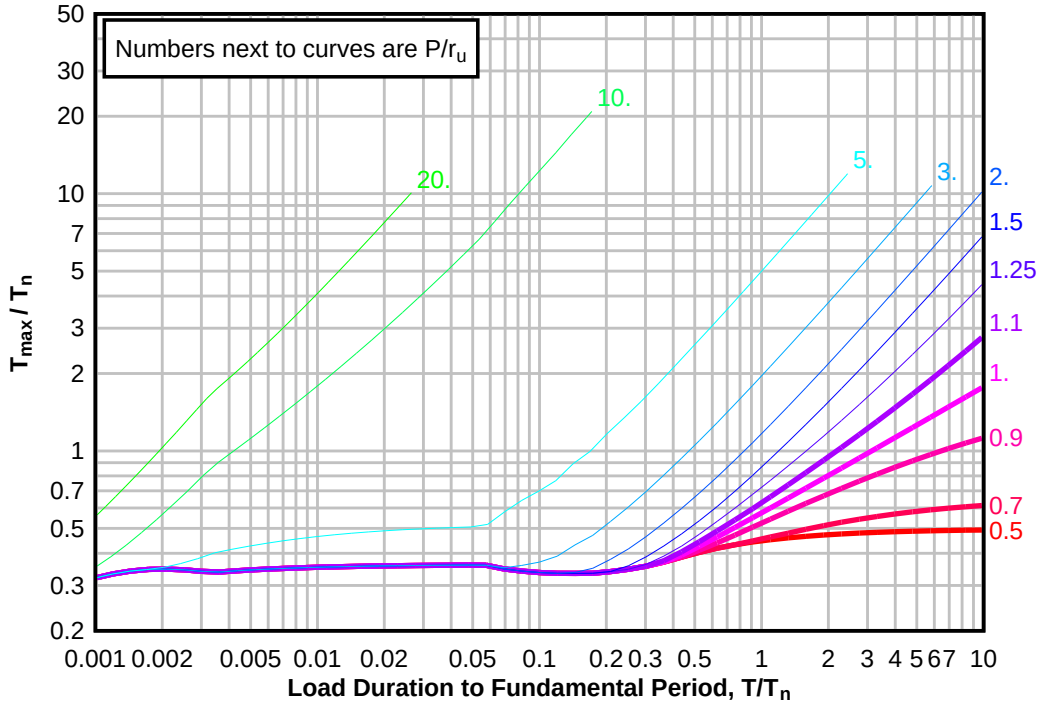


Figure 3-203(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.121, C2 = 300)

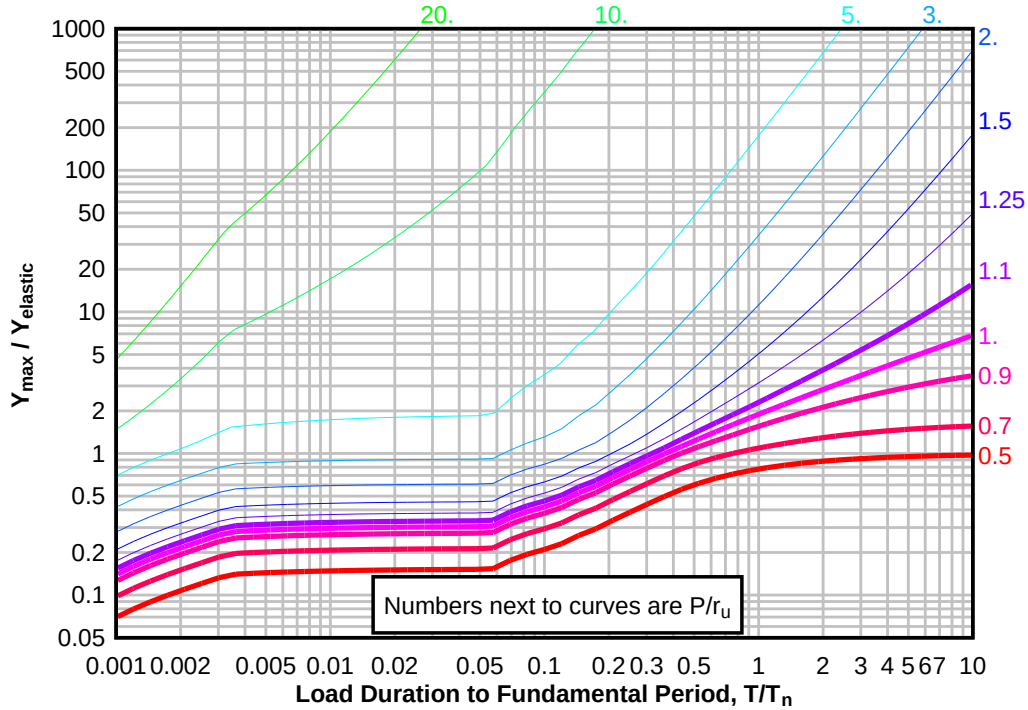


Figure 3-203(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.121, C2 = 300)

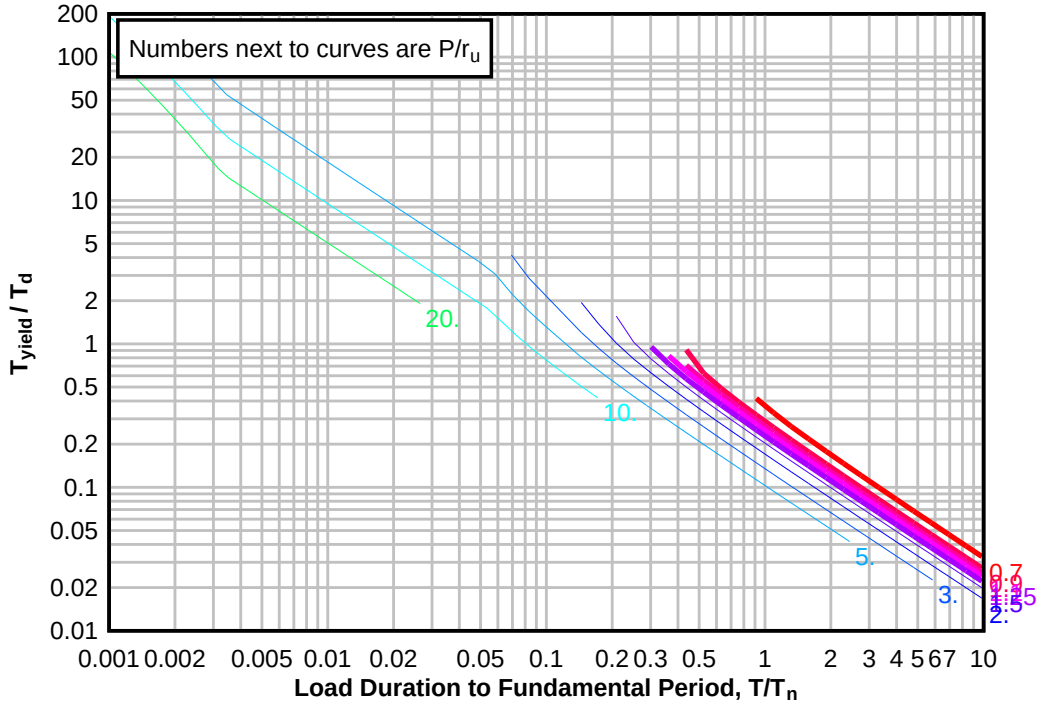


Figure 3-204(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.110, C_2 = 300)

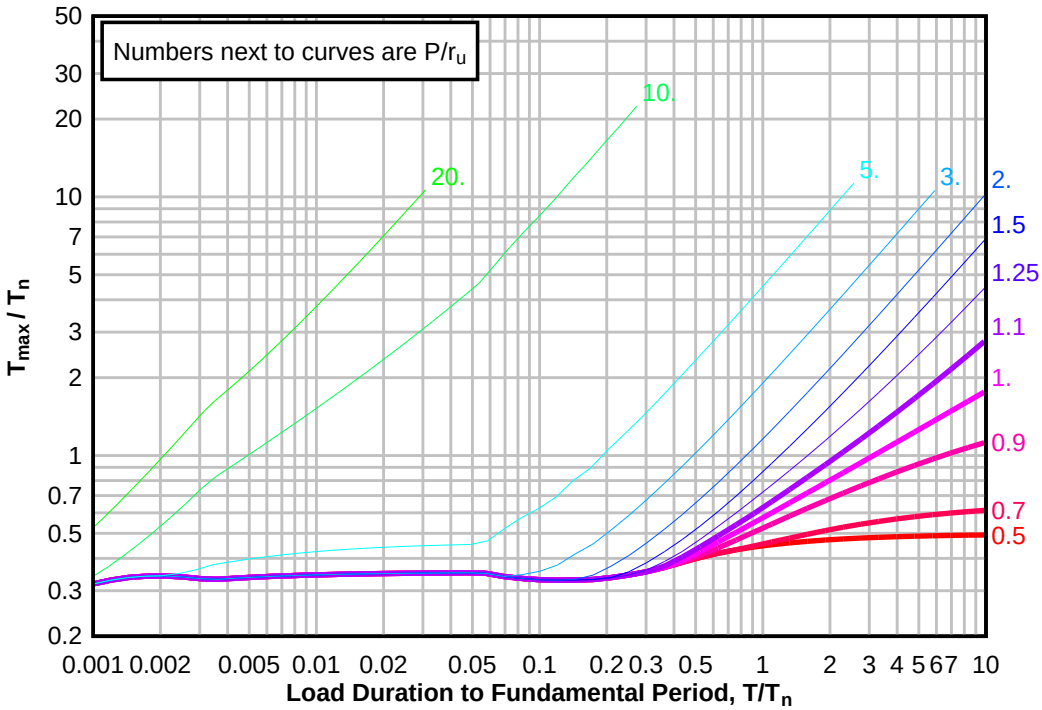


Figure 3-204(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.110, C2 = 300)

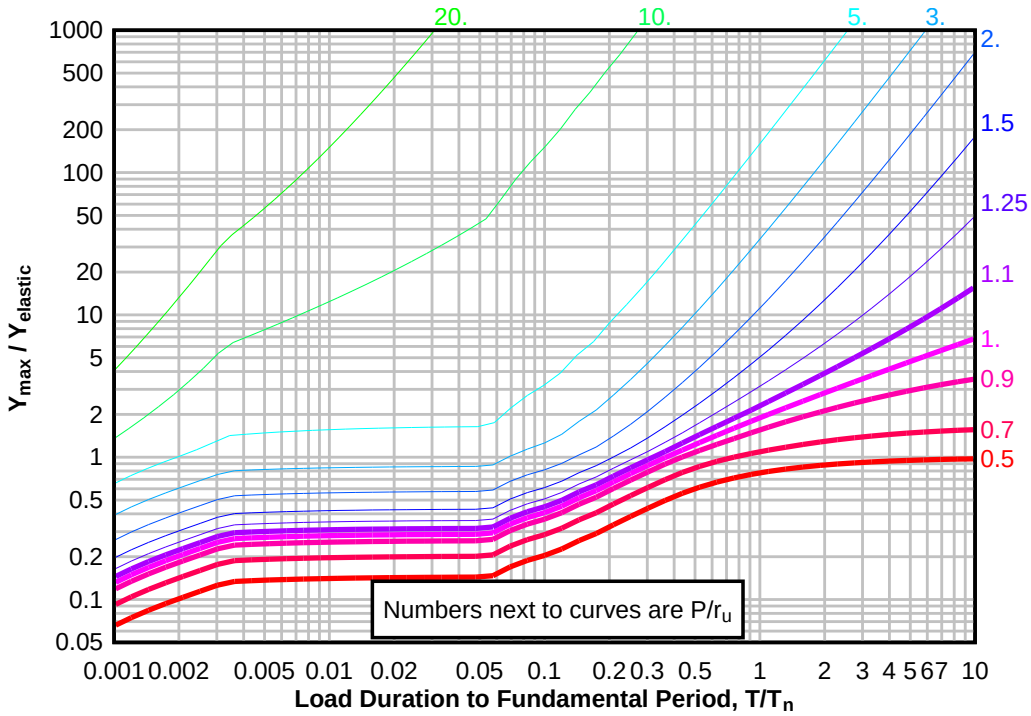


Figure 3-204(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.110, C2 = 300)

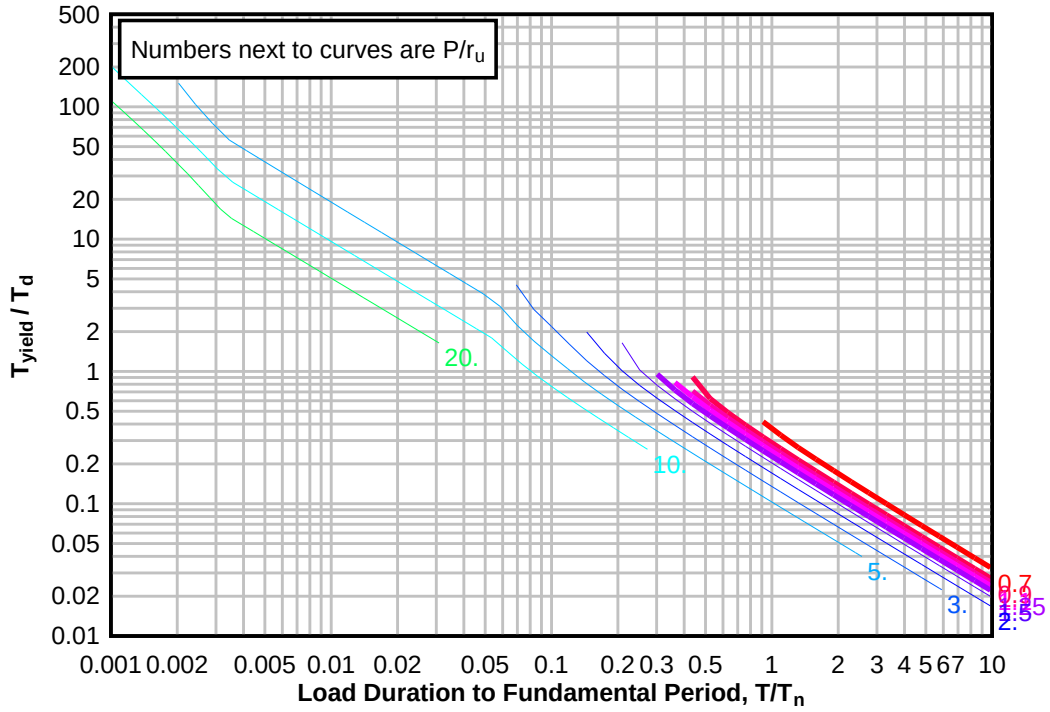


Figure 3-205(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.100, C_2 = 300)

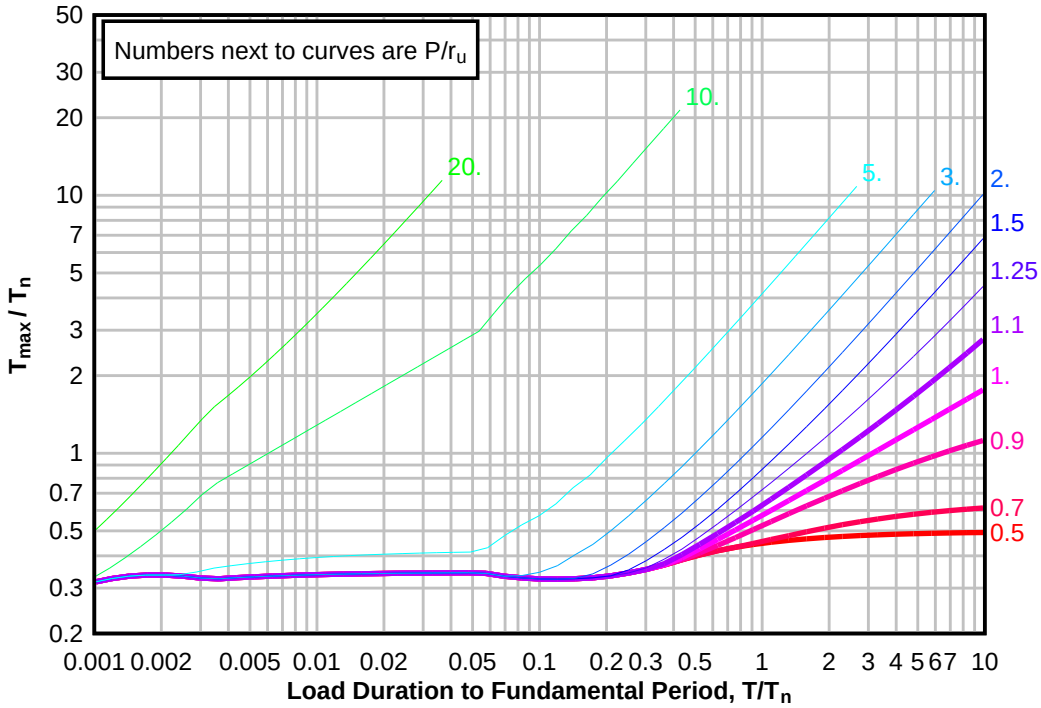


Figure 3-205(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.100, C2 = 300)

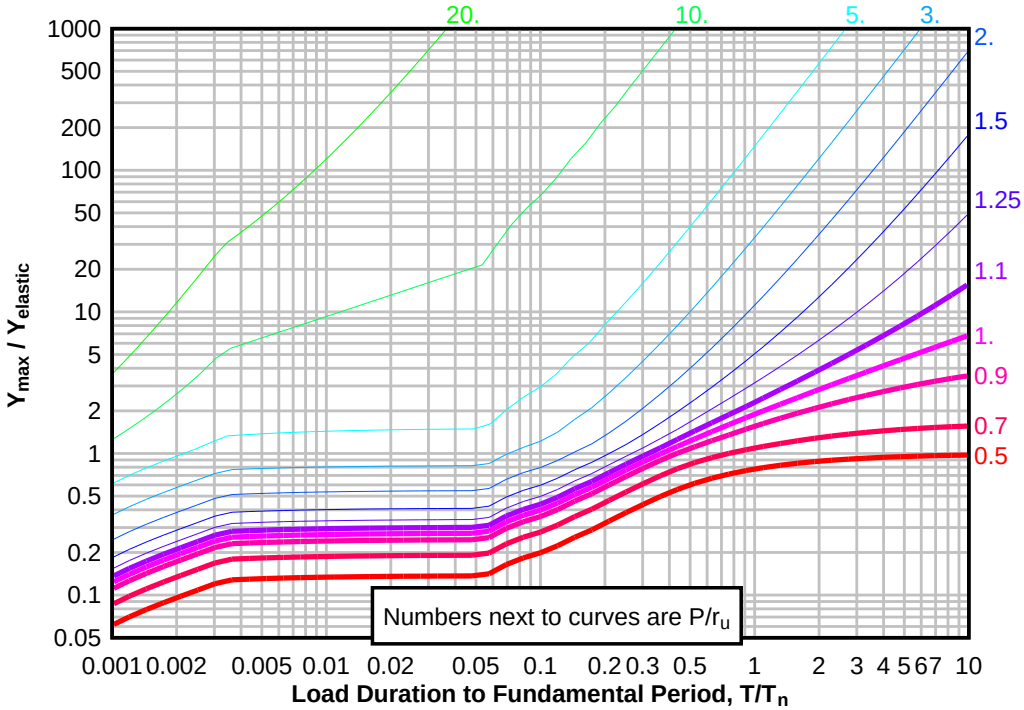


Figure 3-205(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.100, C2 = 300)

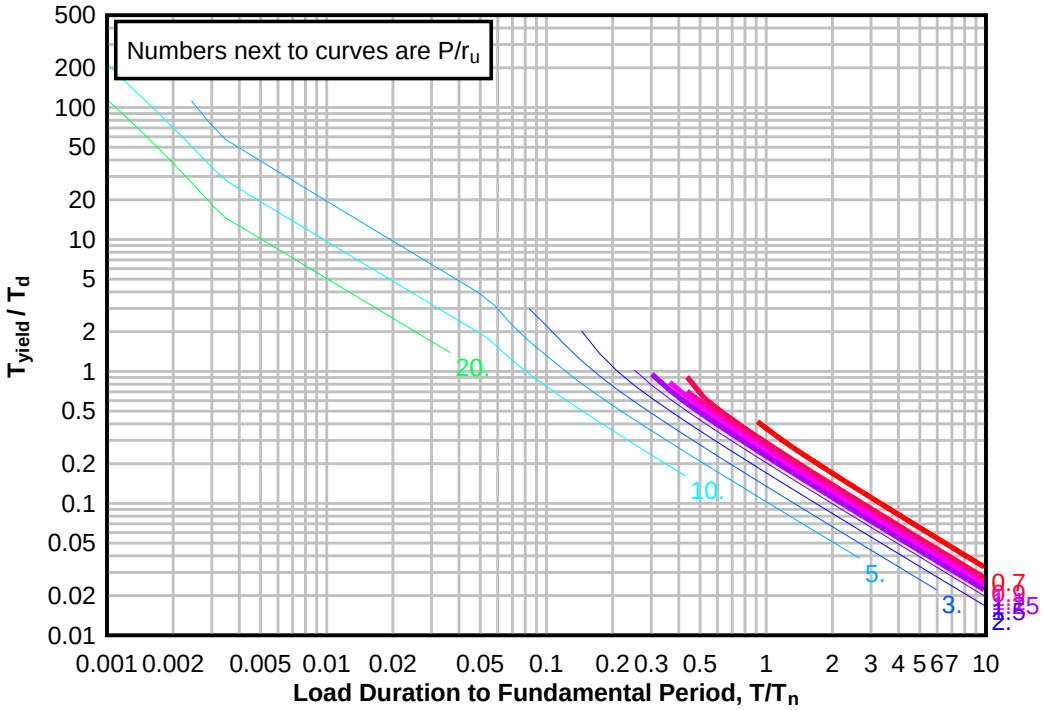


Figure 3-206(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.091, C_2 = 300)

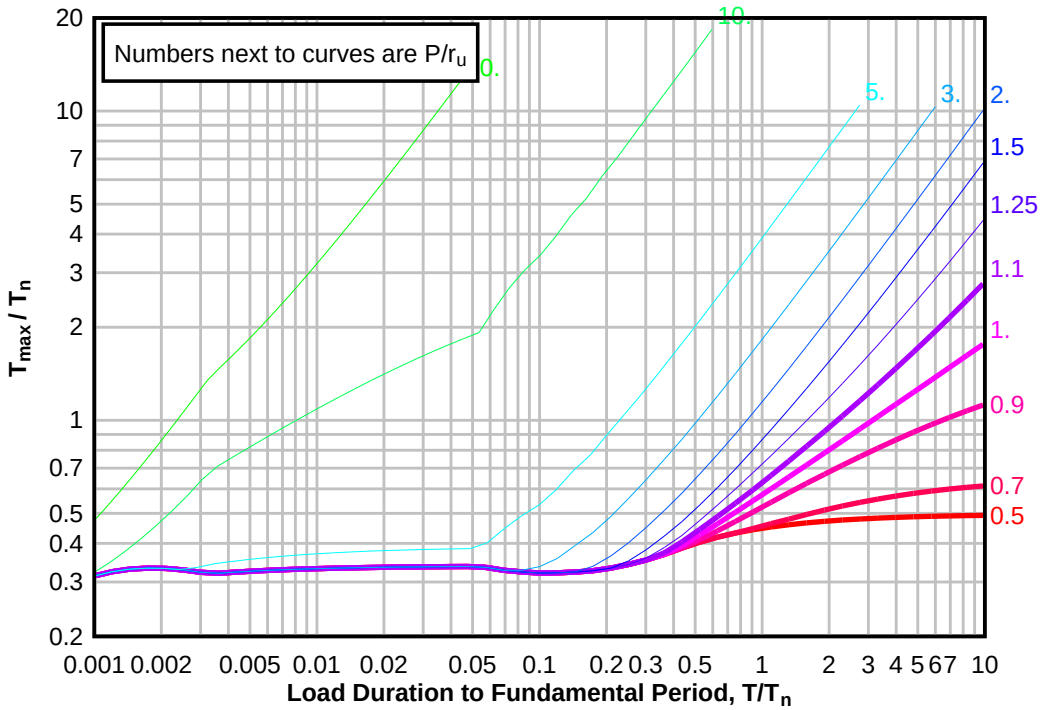


Figure 3-206(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.091, C2 = 300)

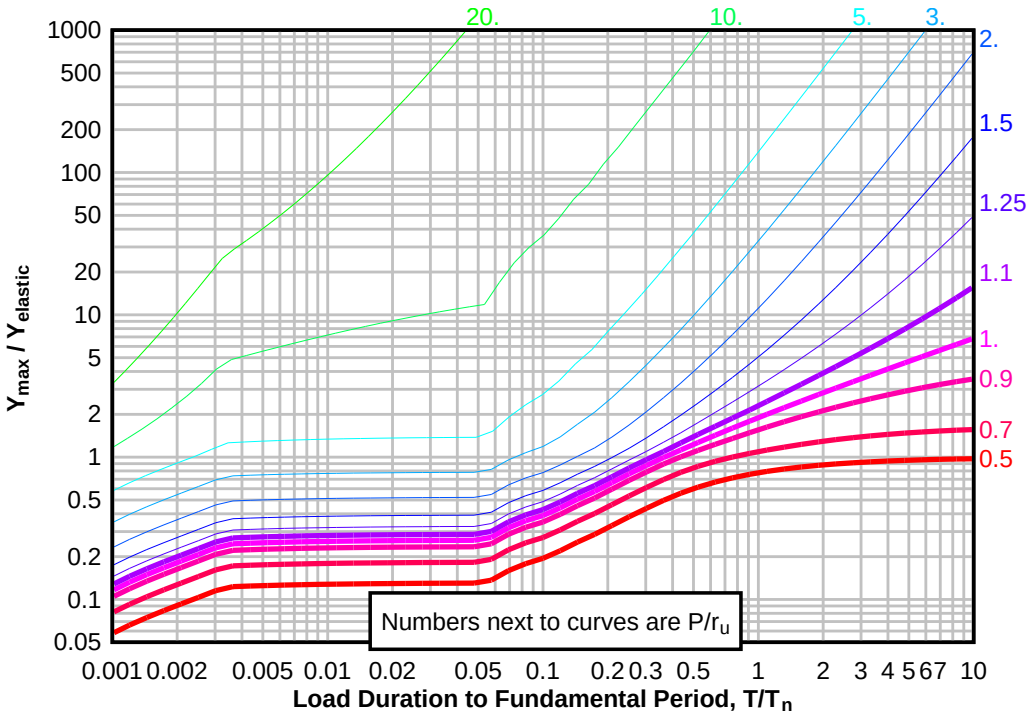


Figure 3-206(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.091, C2 = 300)

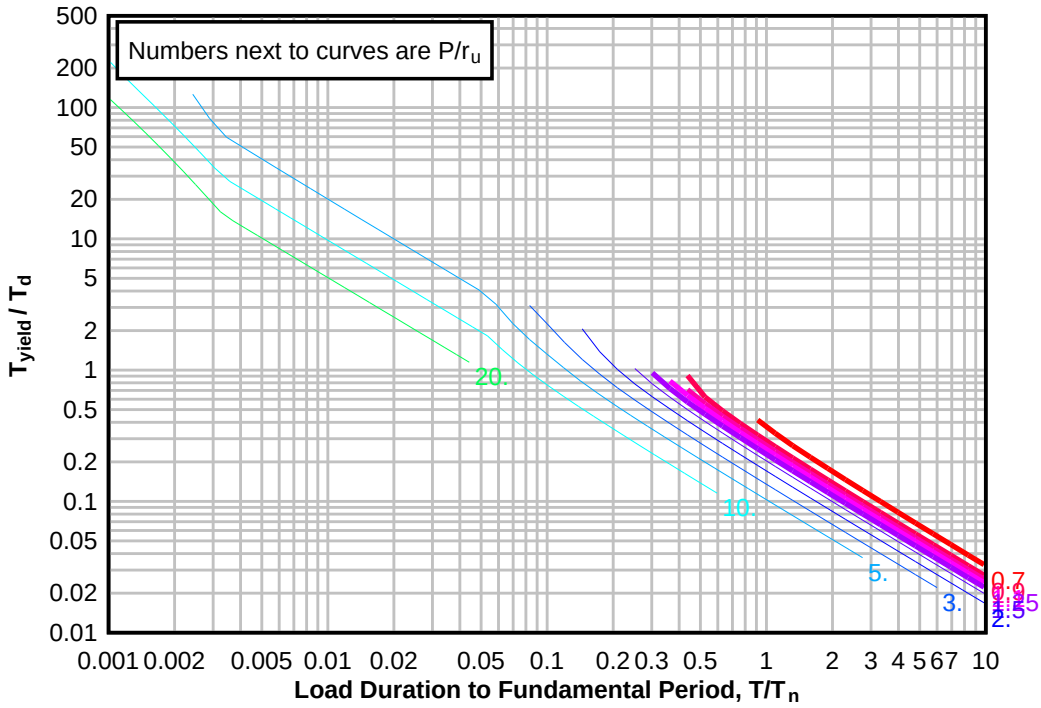


Figure 3-207(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.083, C_2 = 300)

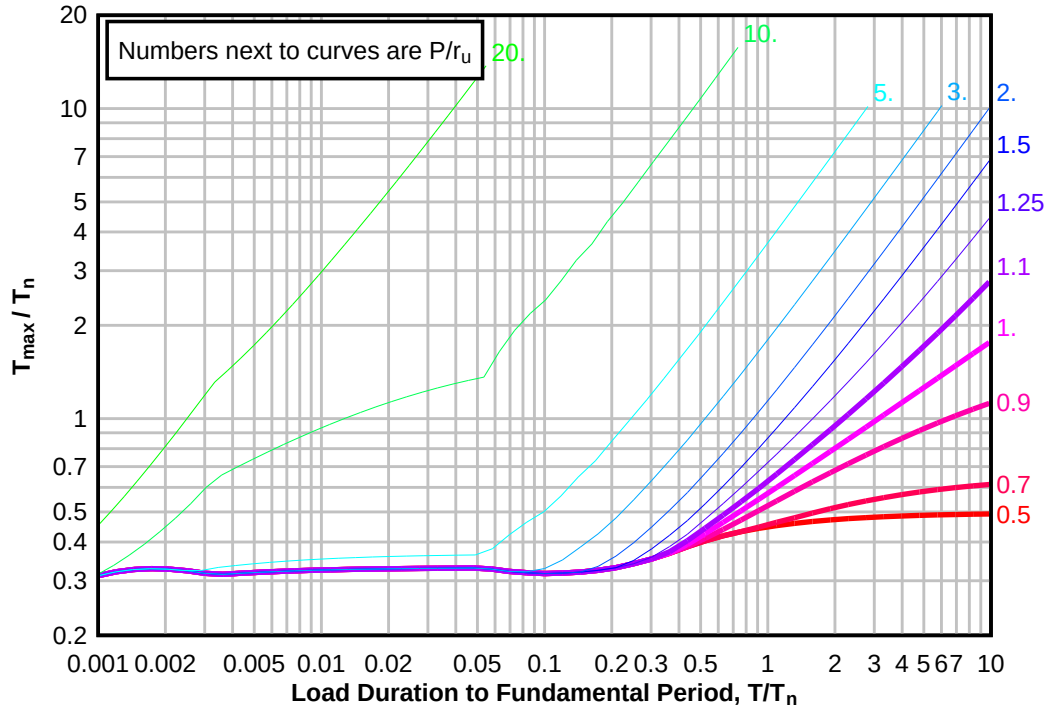


Figure 3-207(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.083, C2 = 300)

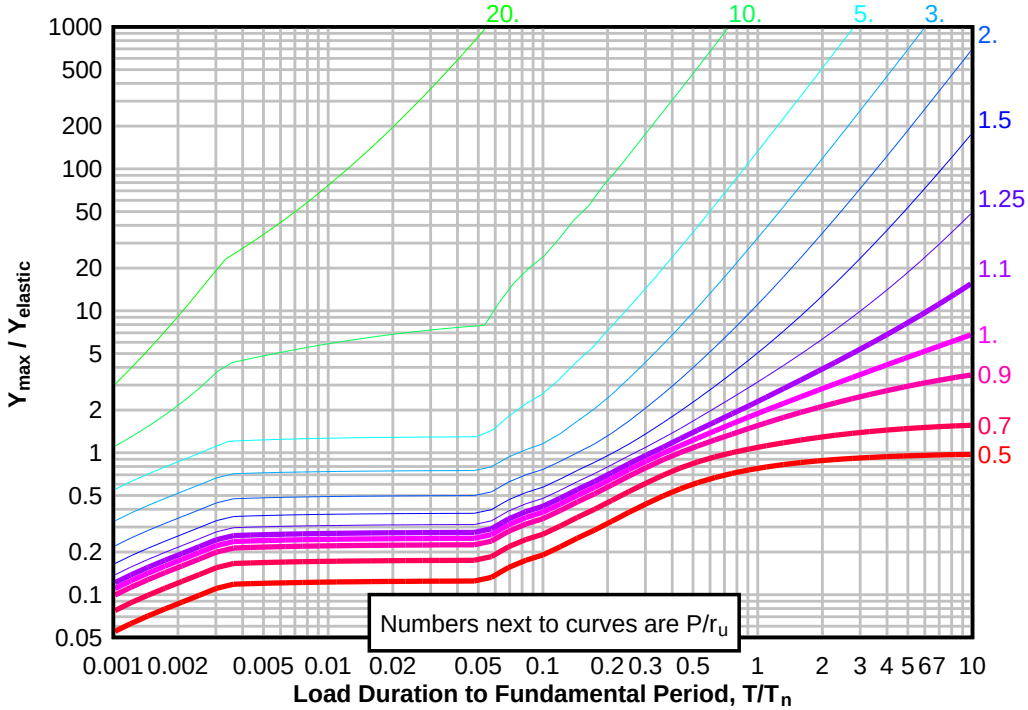


Figure 3-207(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.083, C2 = 300)

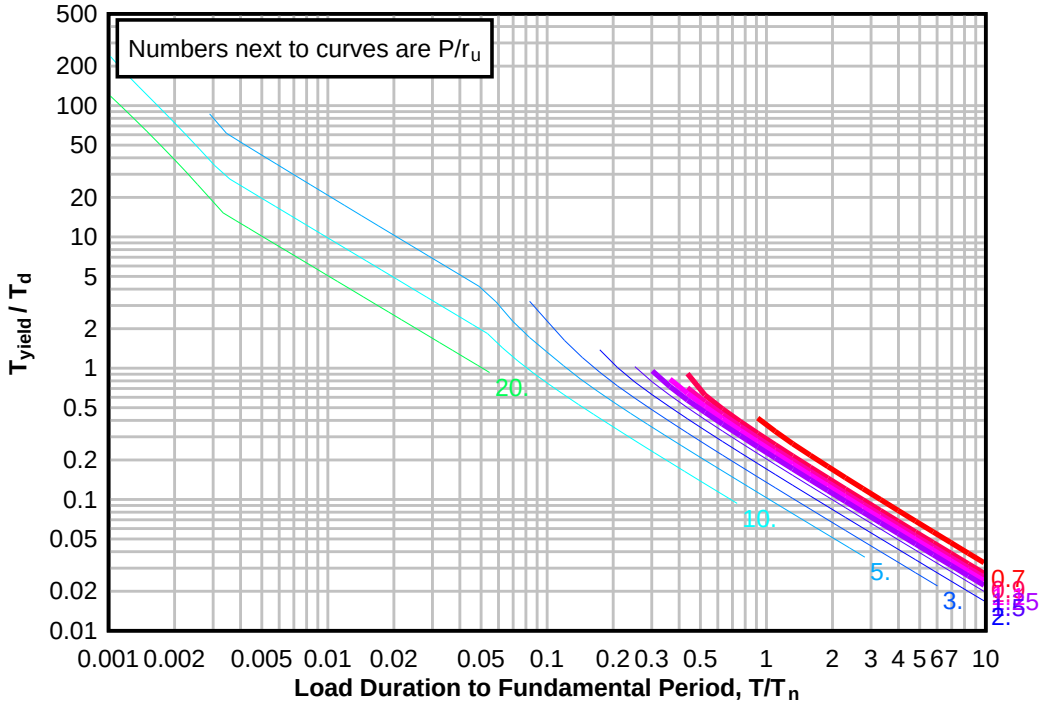


Figure 3-208(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.075, C_2 = 300)

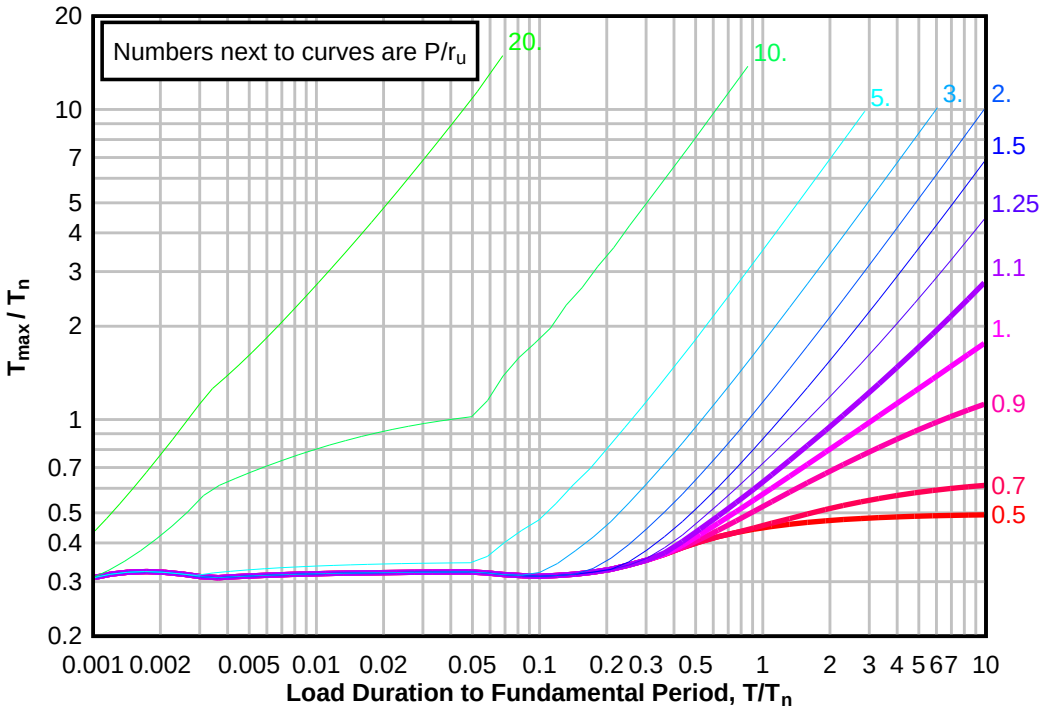


Figure 3-208(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.075, C2 = 300)

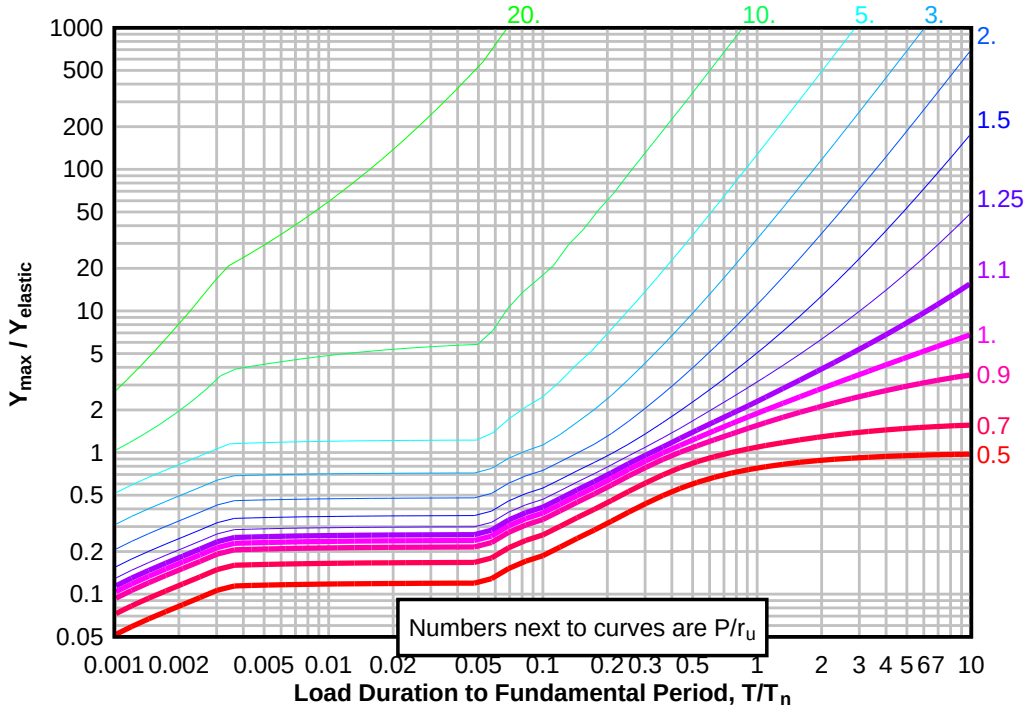


Figure 3-208(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.075, C2 = 300)

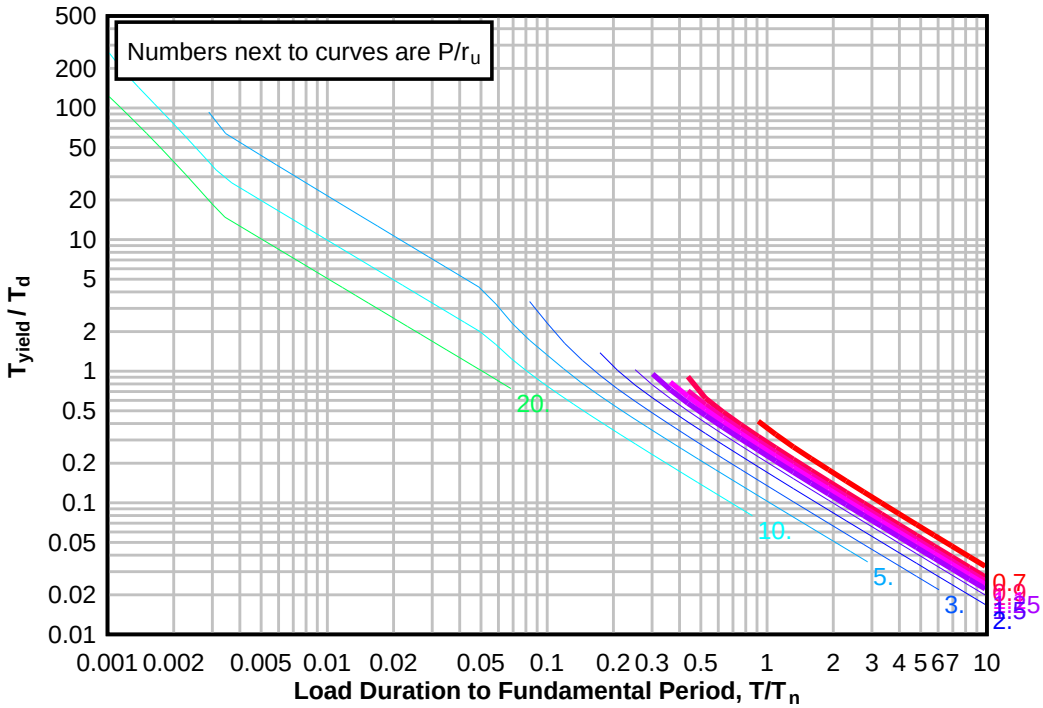


Figure 3-209(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.068, C_2 = 300)

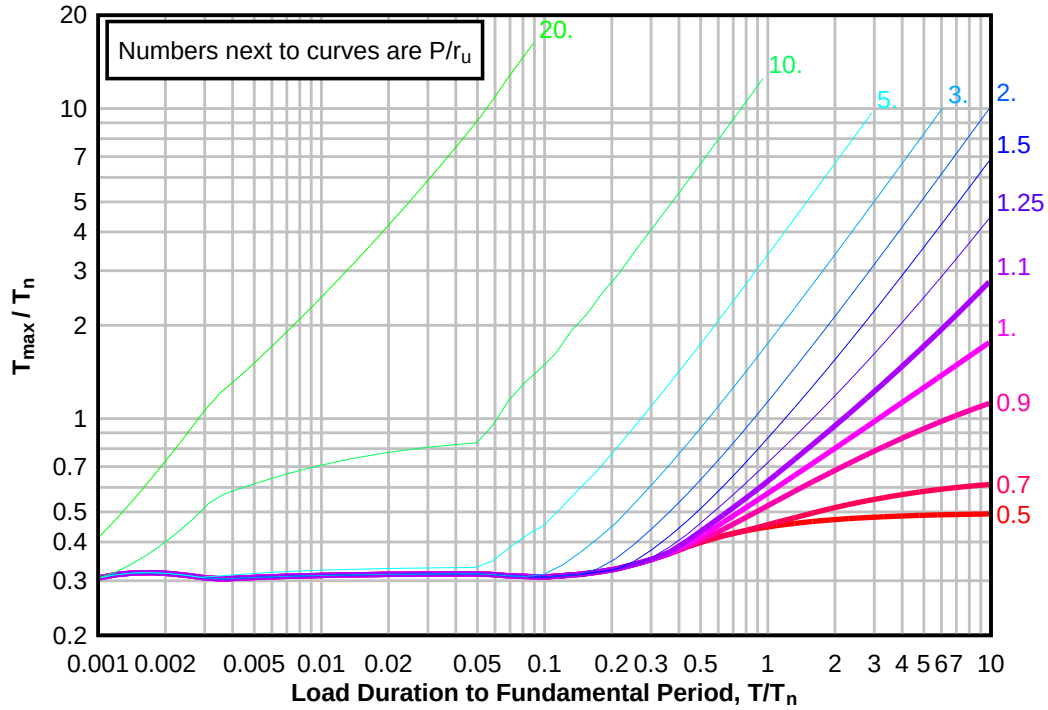


Figure 3-209(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.068, C2 = 300)

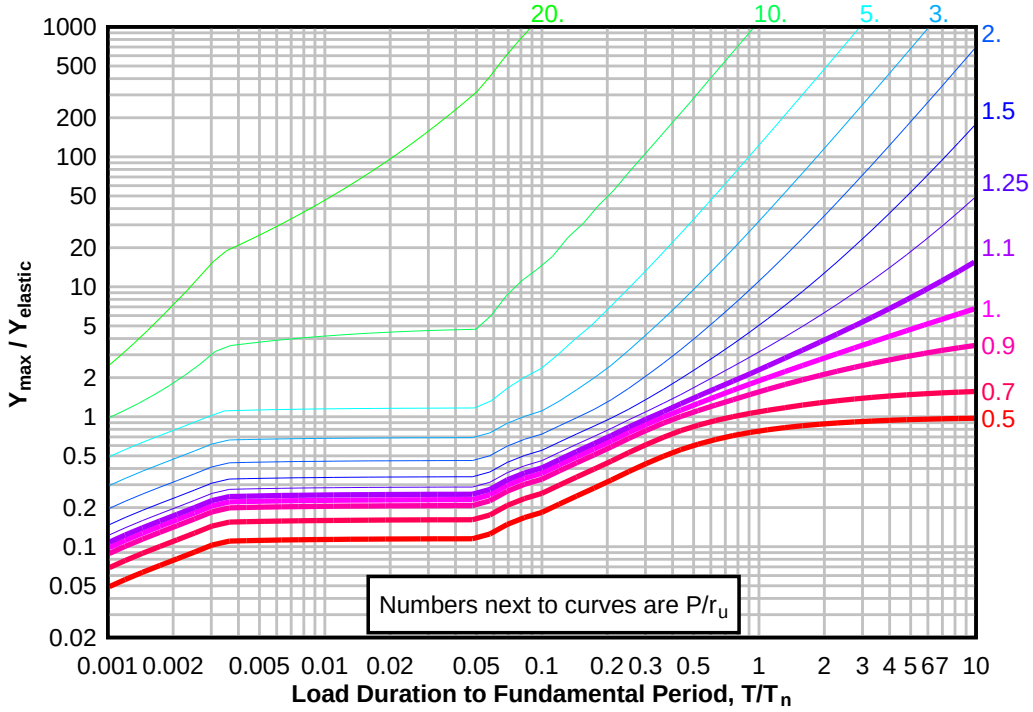


Figure 3-209(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.068, C2 = 300)

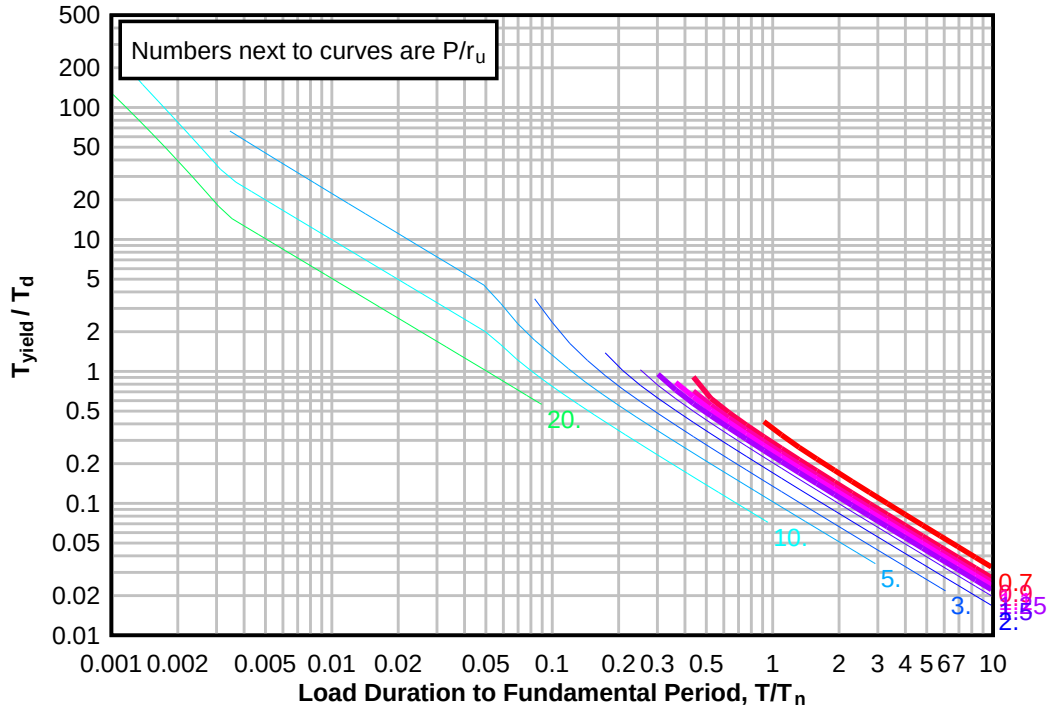


Figure 3-210(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.056, C_2 = 300)

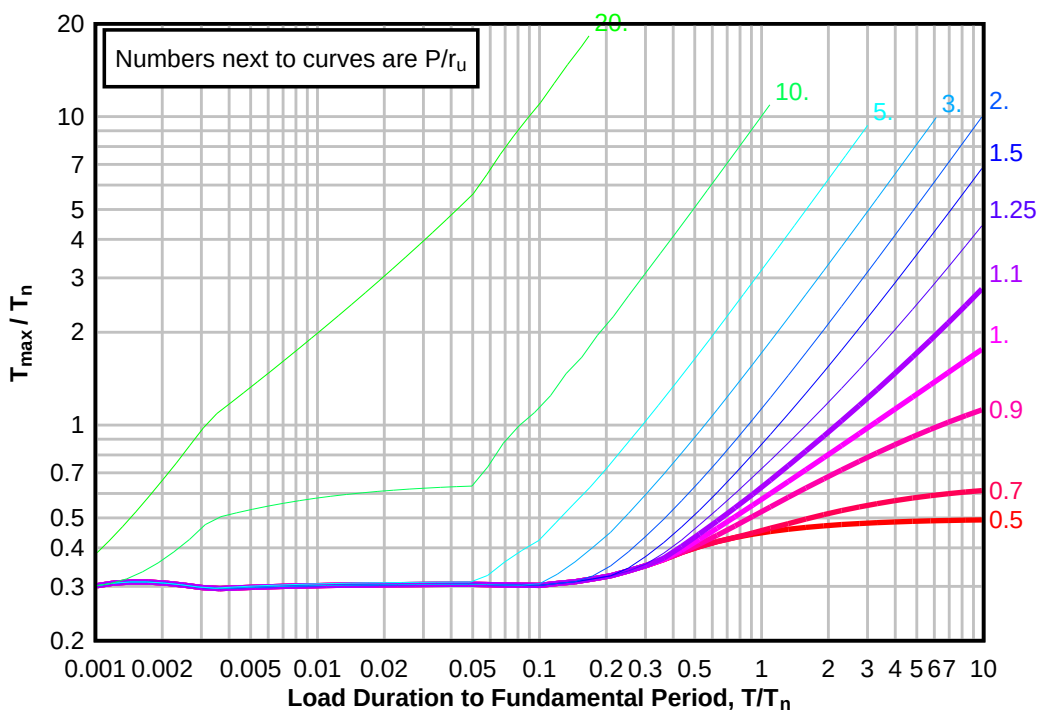


Figure 3-210(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.056, C2 = 300)

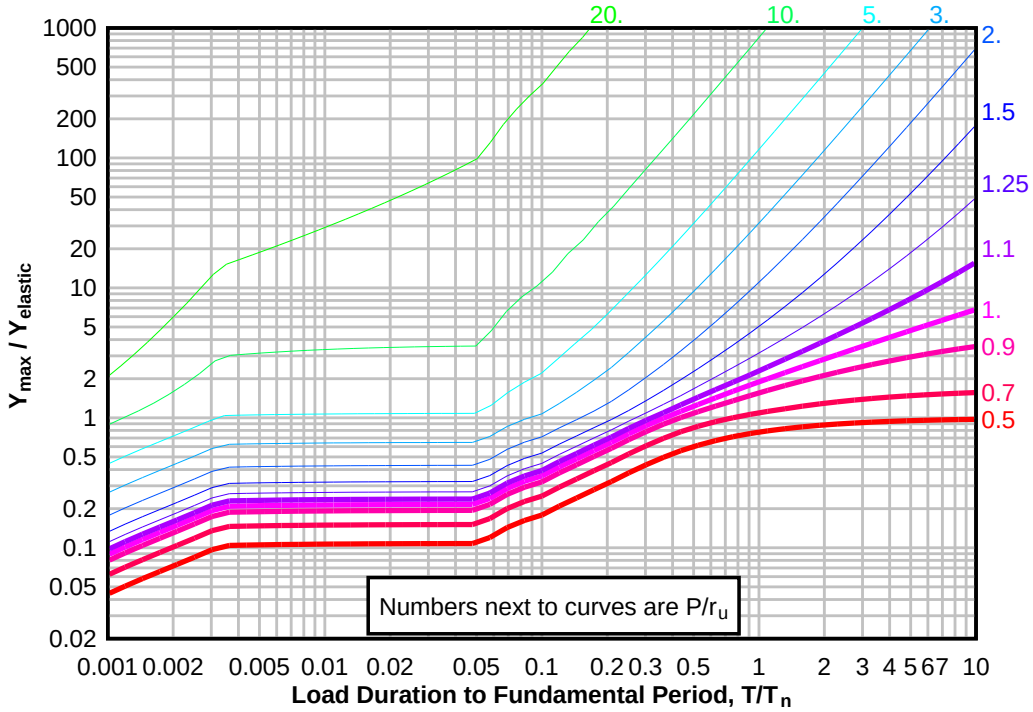


Figure 3-210(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.056, C2 = 300)

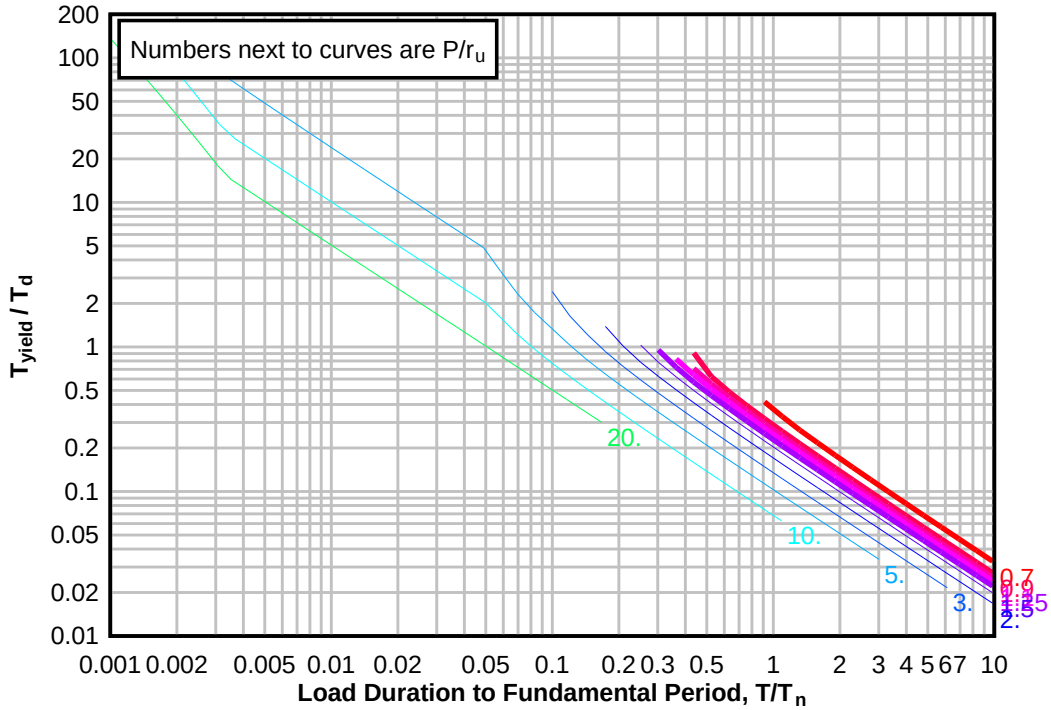


Figure 3-211(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.046, C_2 = 300)

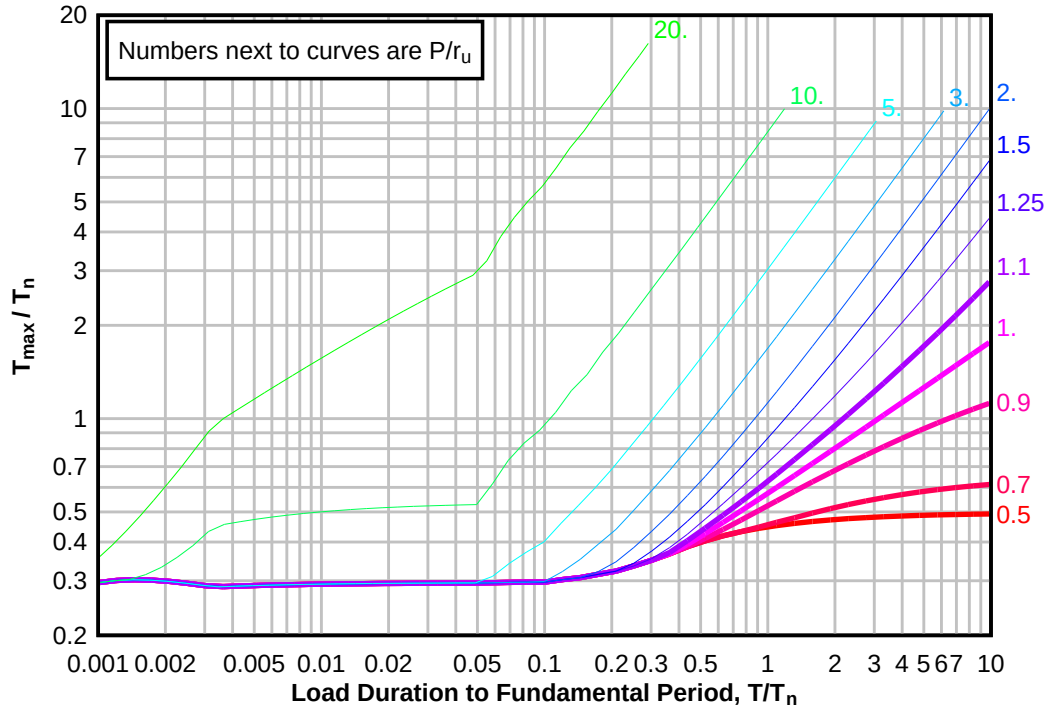


Figure 3-211(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.046, C2 = 300)

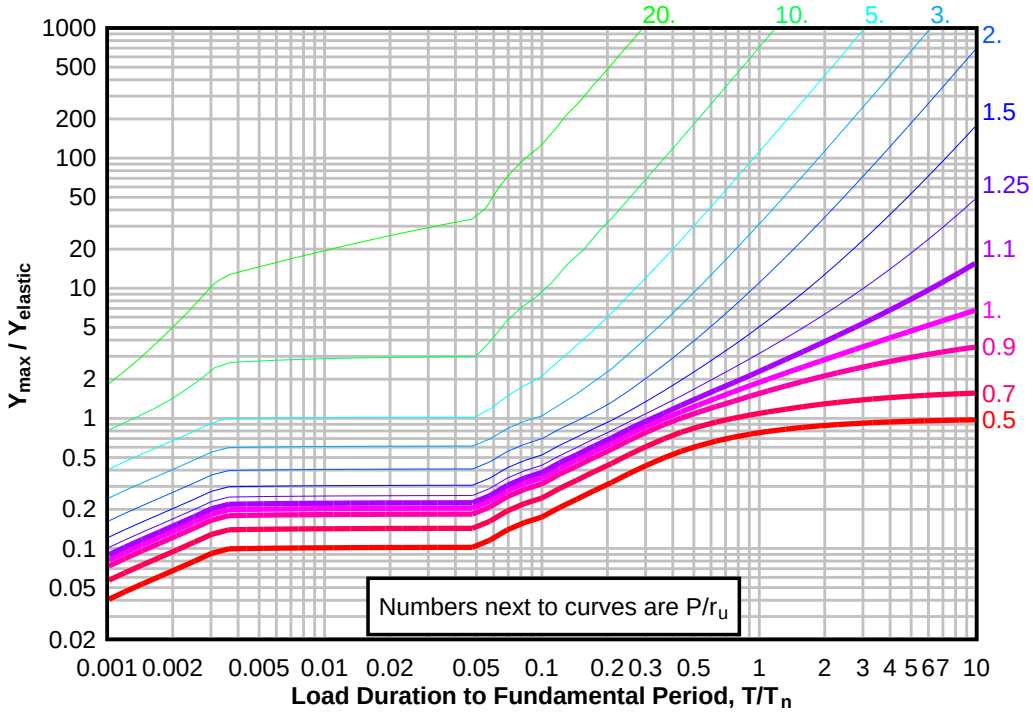


Figure 3-211(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.046, C2 = 300)

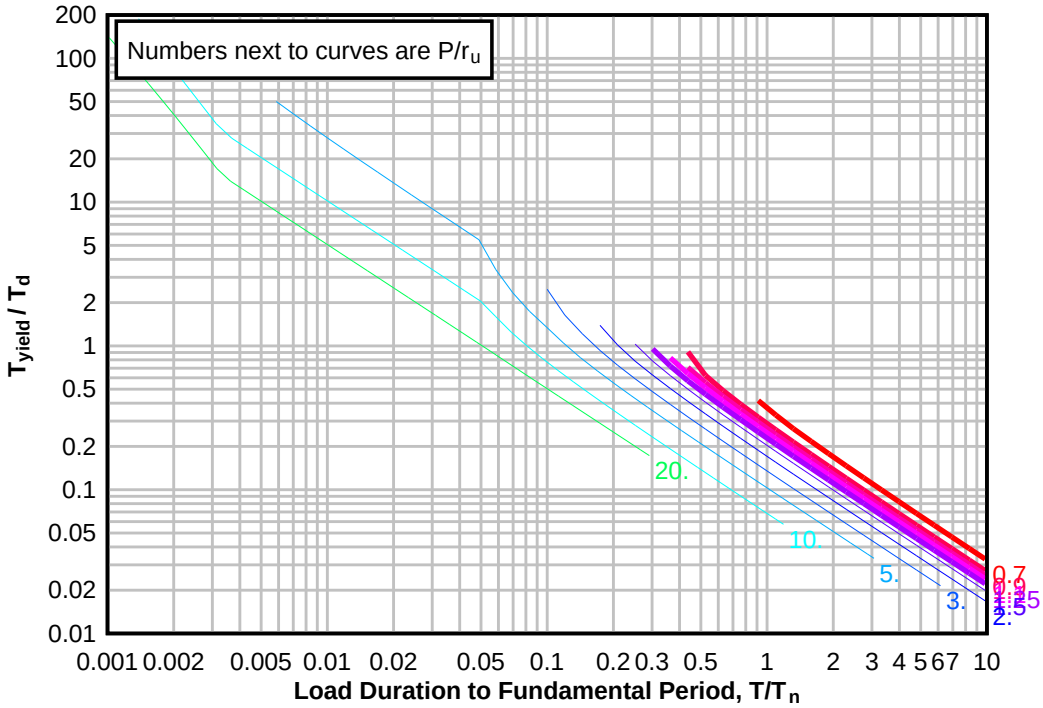


Figure 3-212(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.042, C_2 = 300)

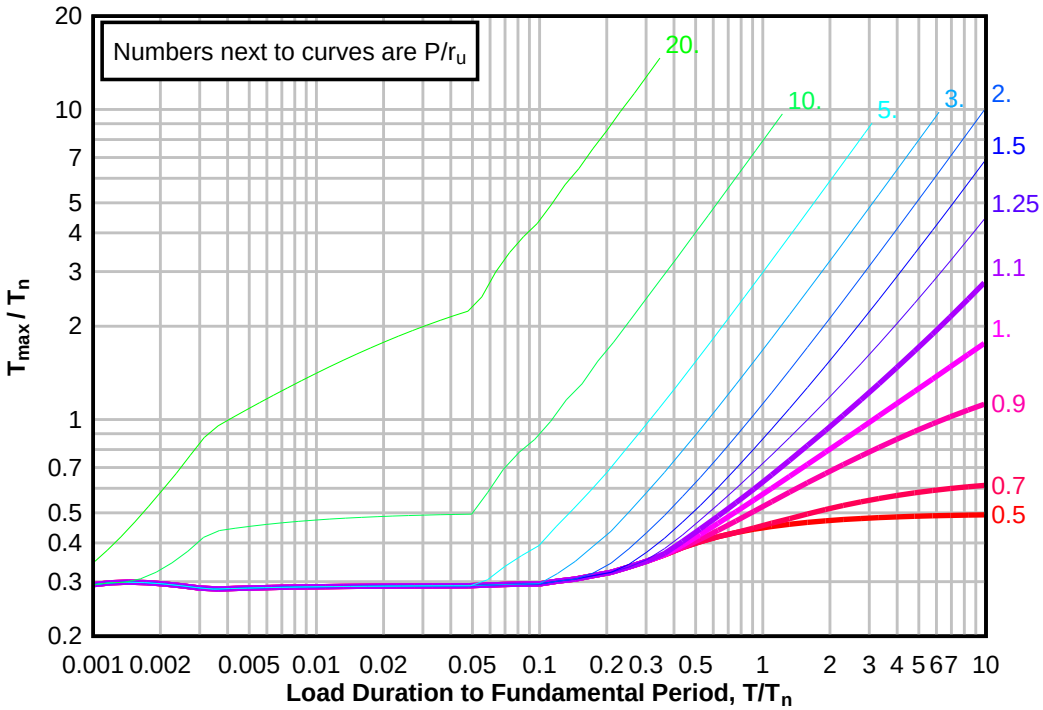


Figure 3-212(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.042, C2 = 300)

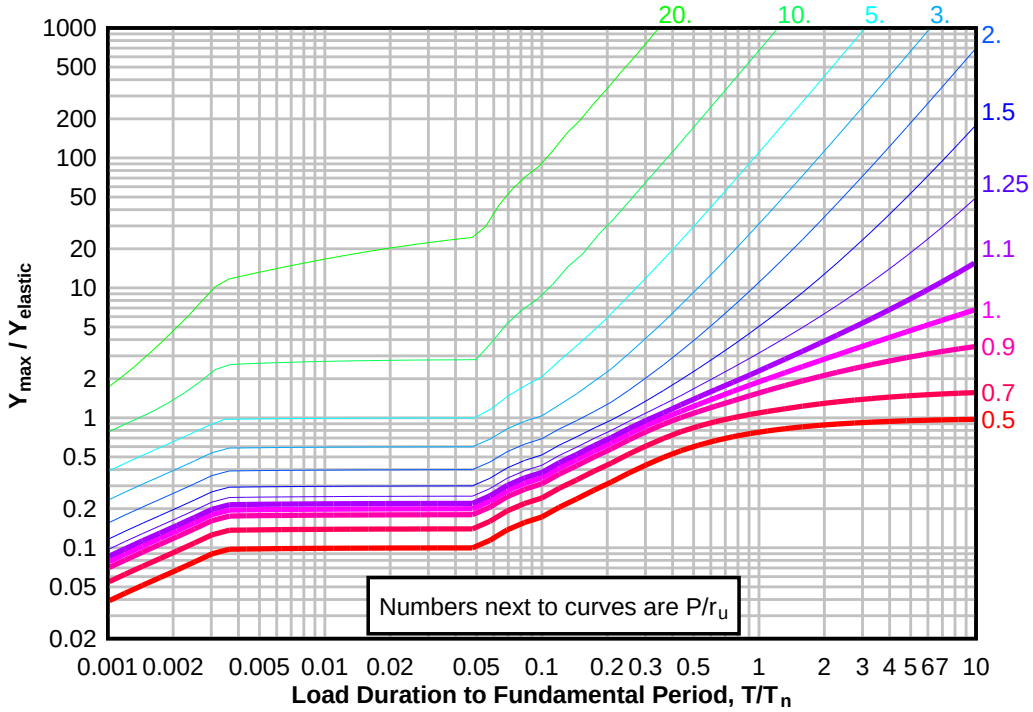


Figure 3-212(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.042, C2 = 300)

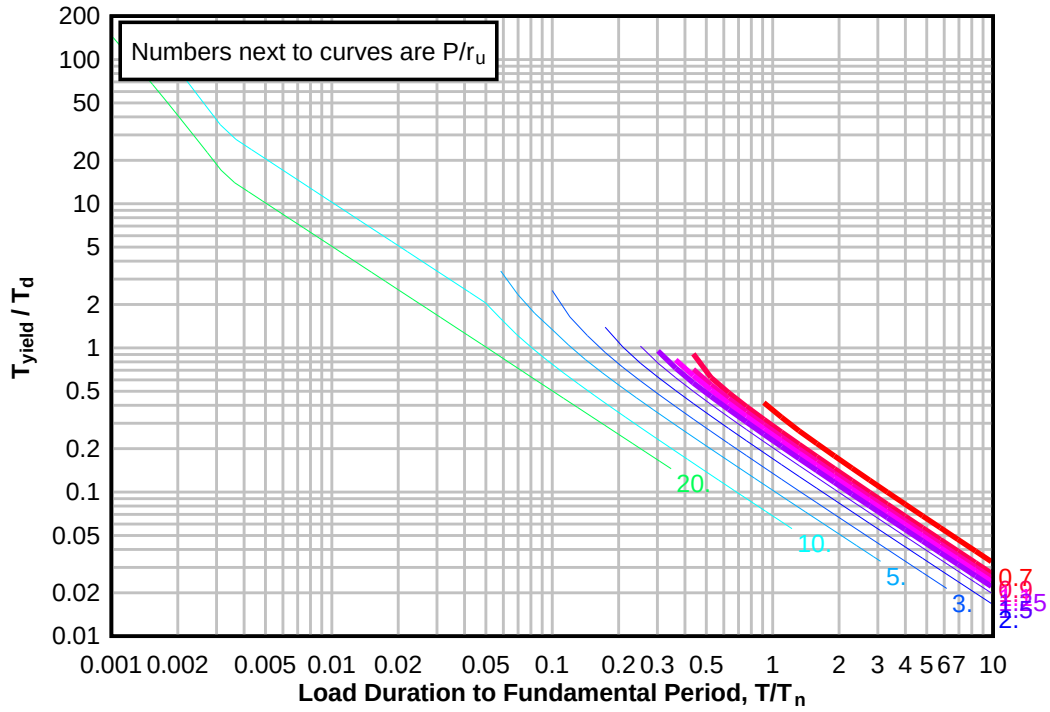


Figure 3-213(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.032, C_2 = 300)

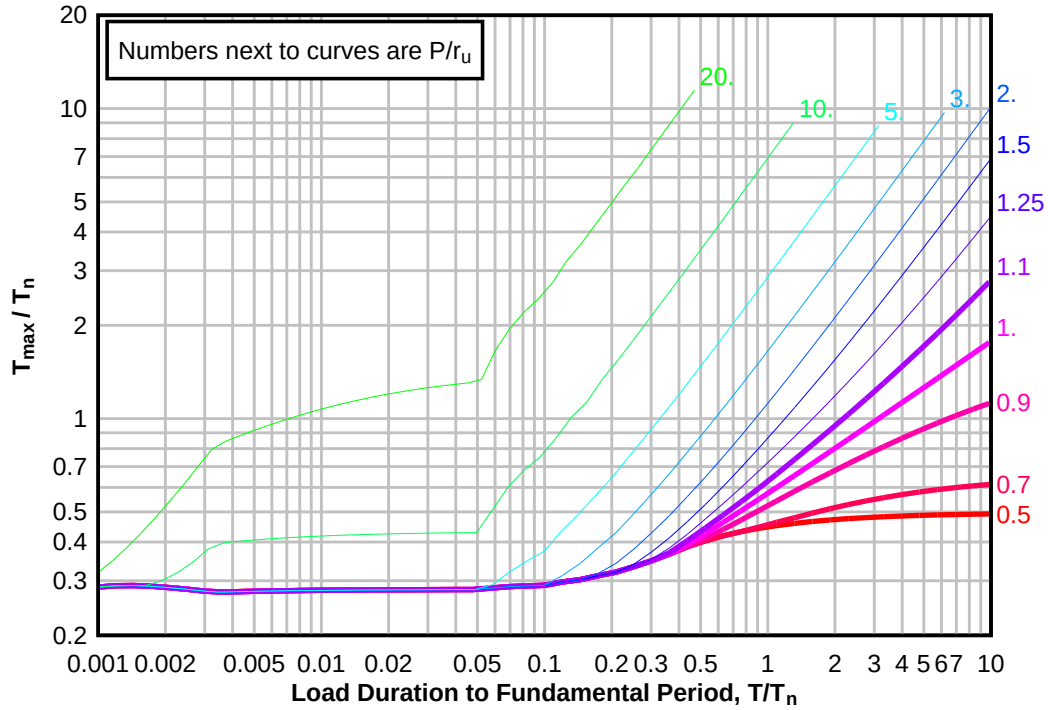


Figure 3-213(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.032, C2 = 300)

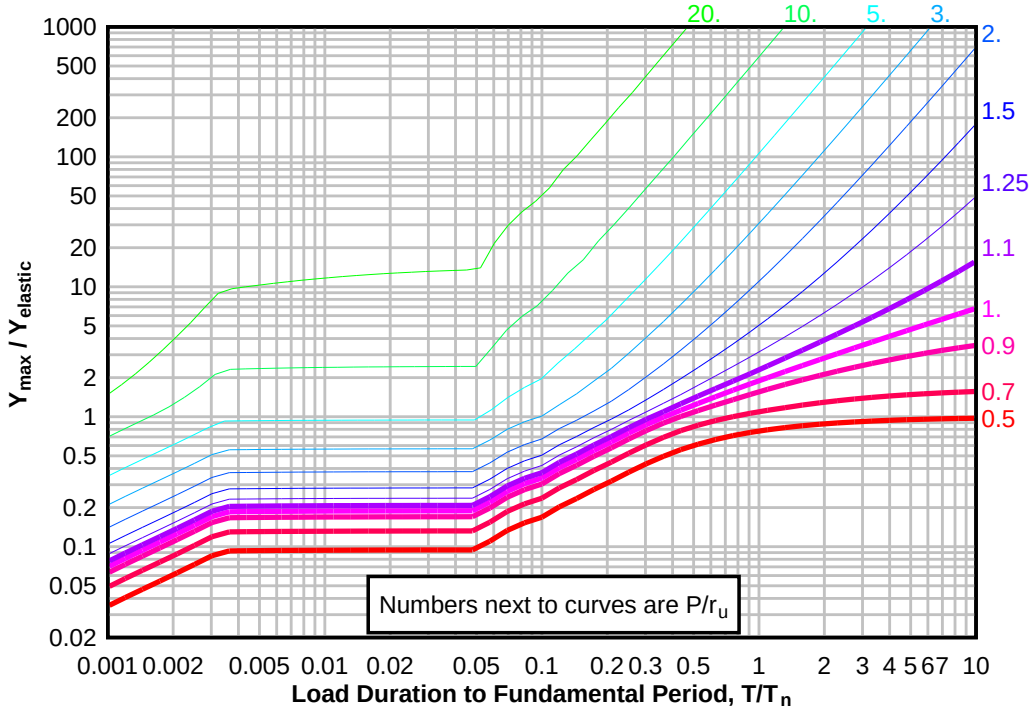


Figure 3-213(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.032, C2 = 300)

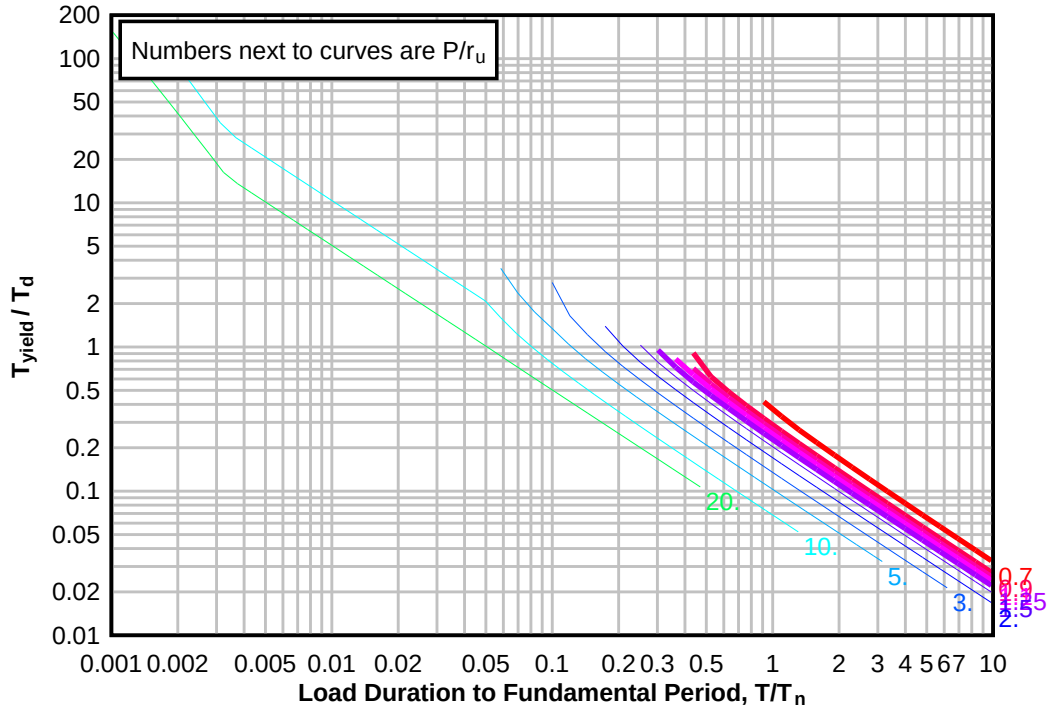


Figure 3-214(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.026, C_2 = 300)

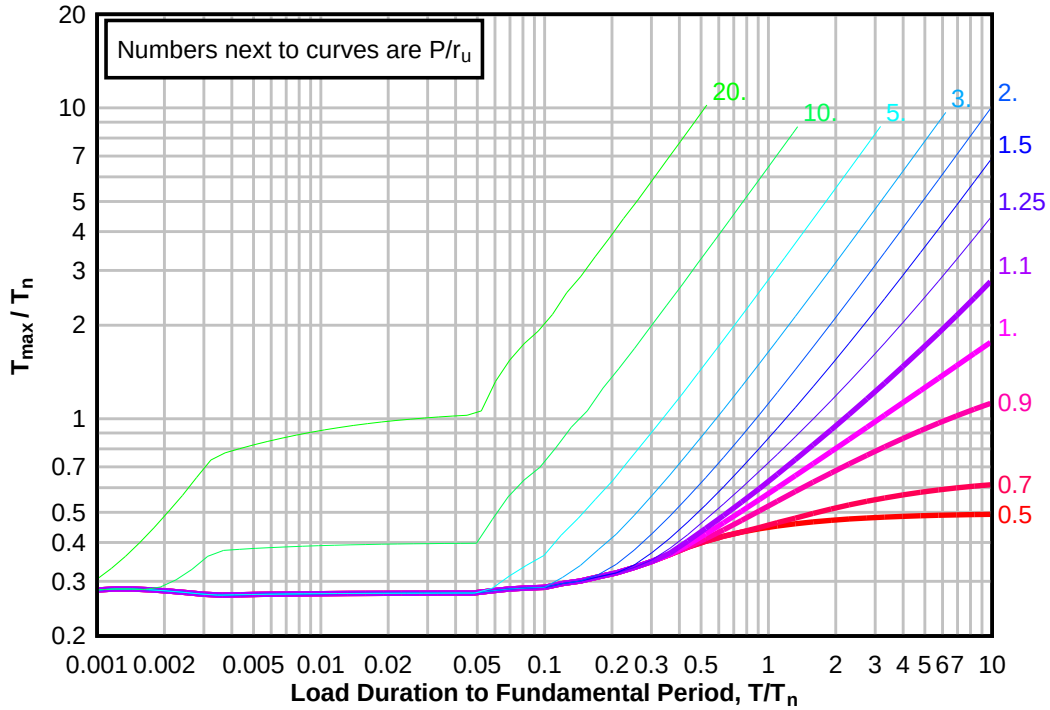


Figure 3-214(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.026, C2 = 300)

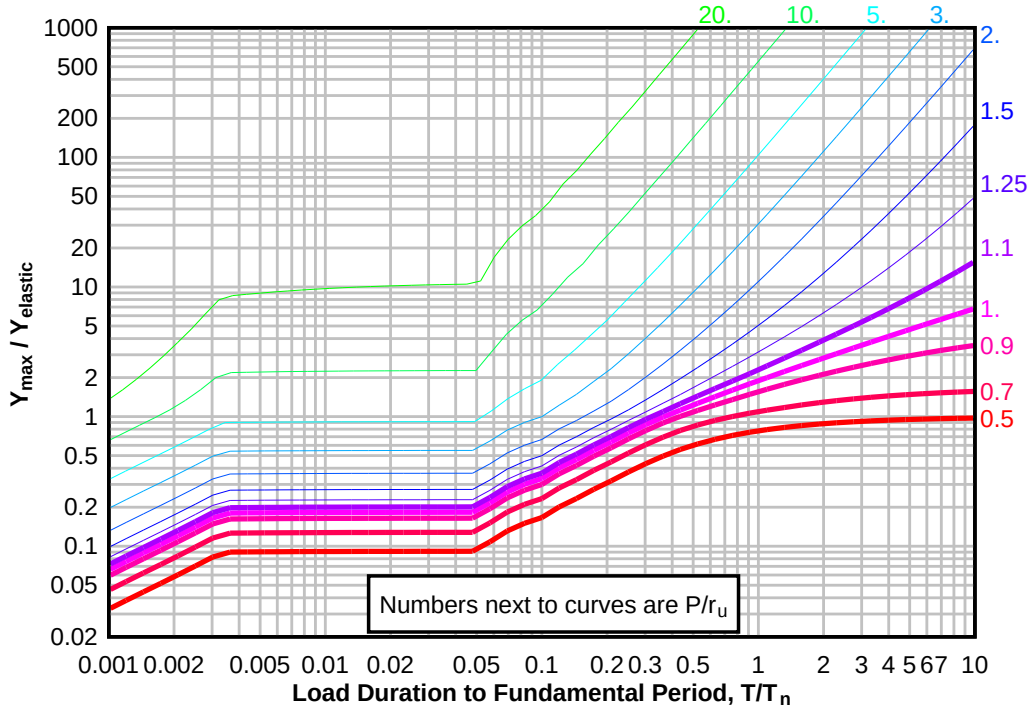


Figure 3-214(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.026, C2 = 300)

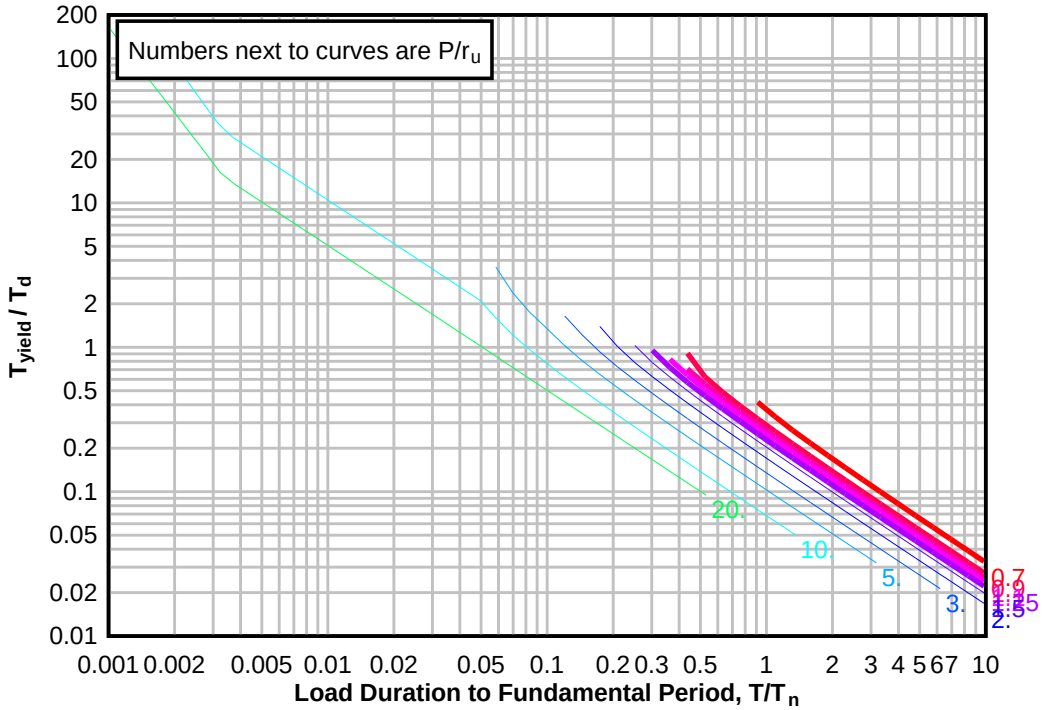


Figure 3-215(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.022, C_2 = 300)

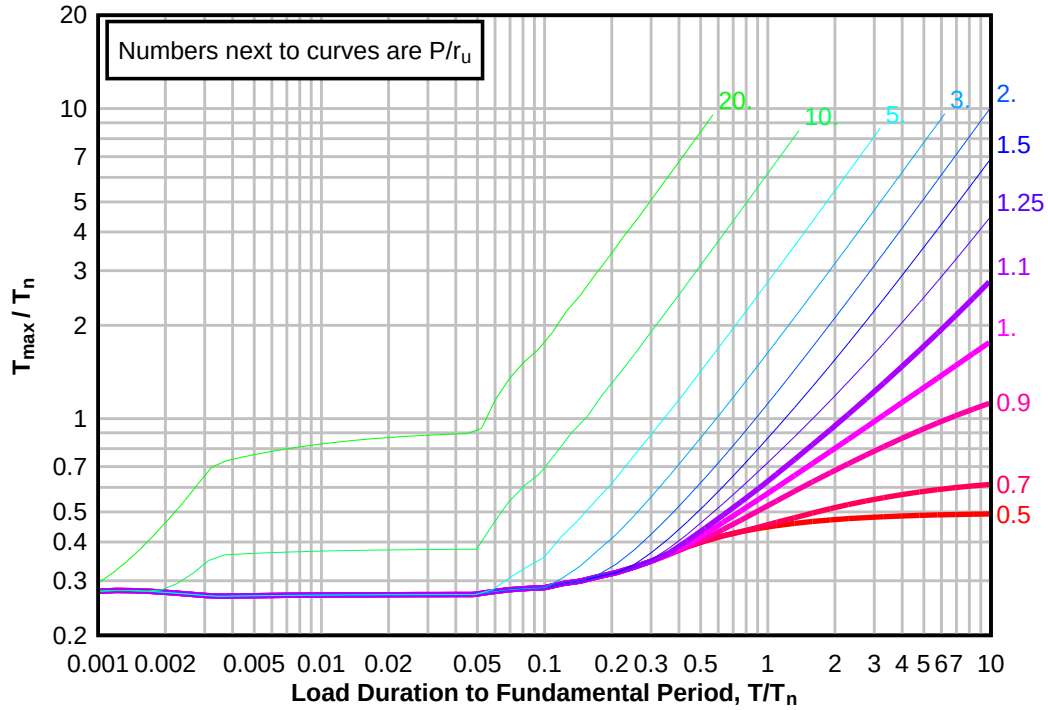


Figure 3-215(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.022, C2 = 300)

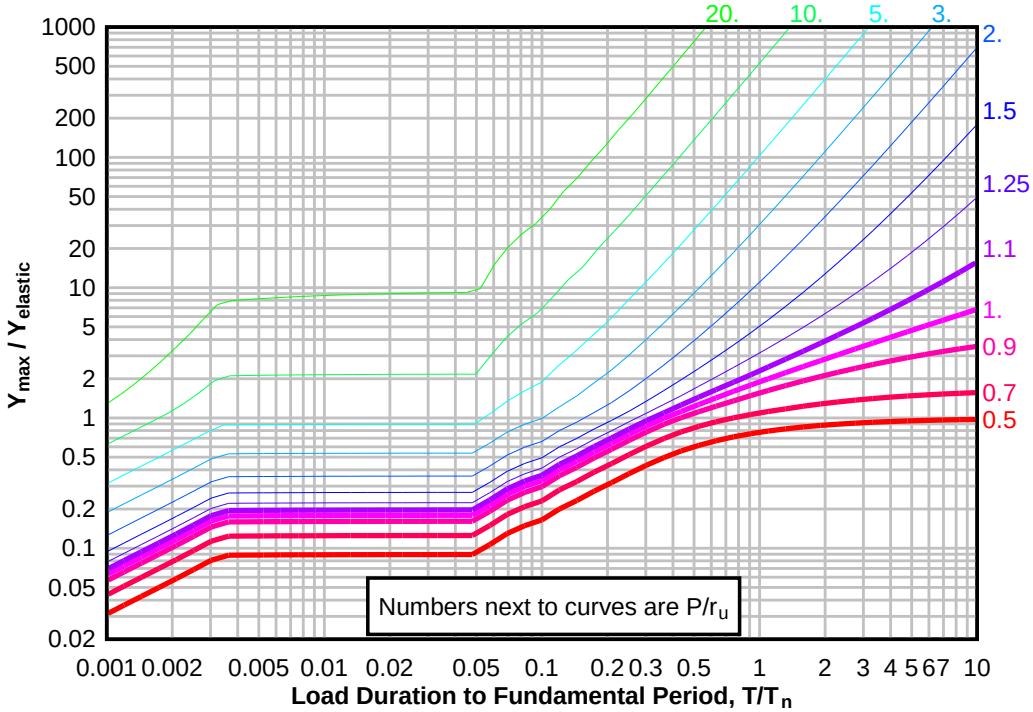


Figure 3-215(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.022, C2 = 300)

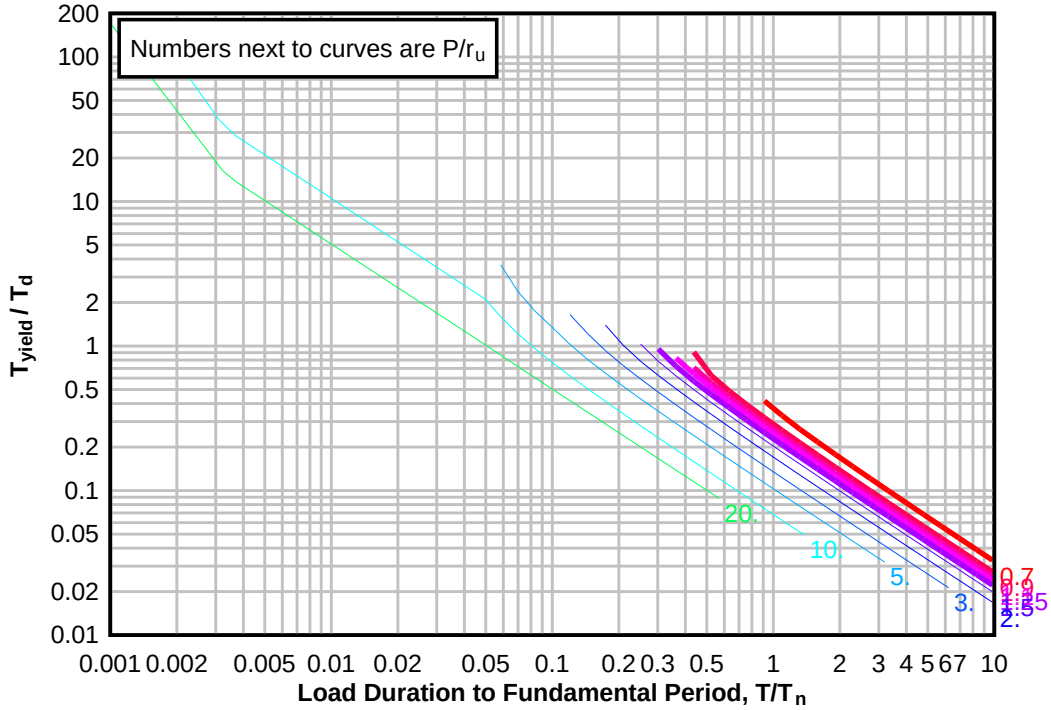


Figure 3-216(a) Maximum Response of Elasto-Plastic, One-Degree-of Freedom System for Bilinear-Triangular Pulse (C_1 = 0.018, C_2 = 300)

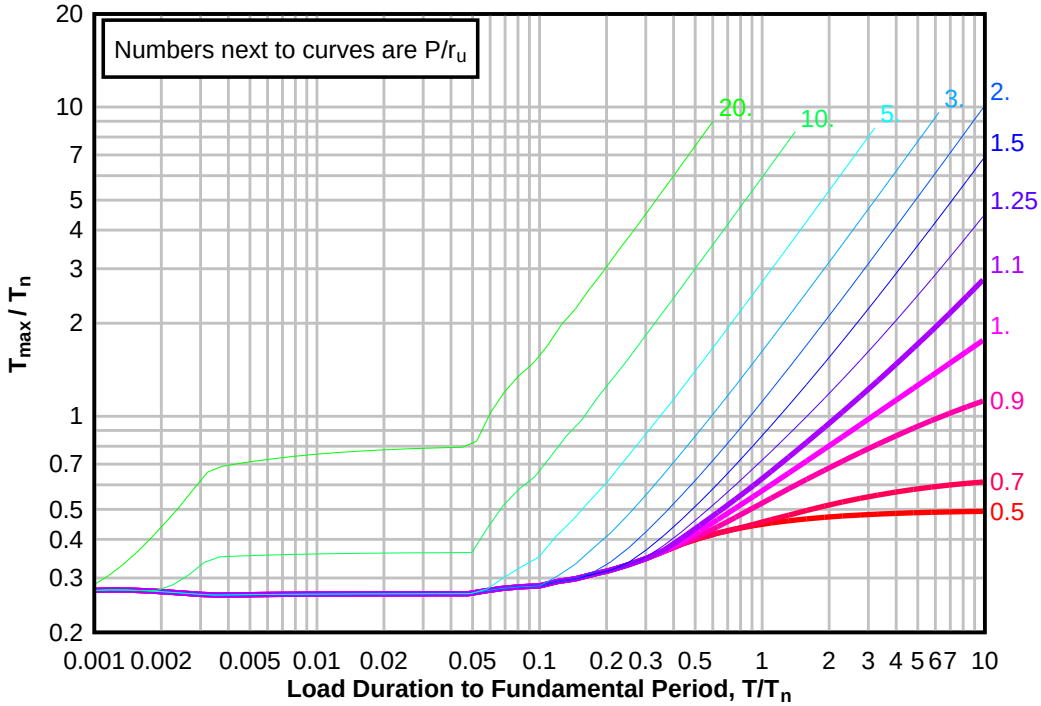


Figure 3-216(b) Maximum Response of Elasto-Plastic, One-Degree-of Freedom System for Bilinear-Triangular Pulse (C1 = 0.018, C2 = 300)

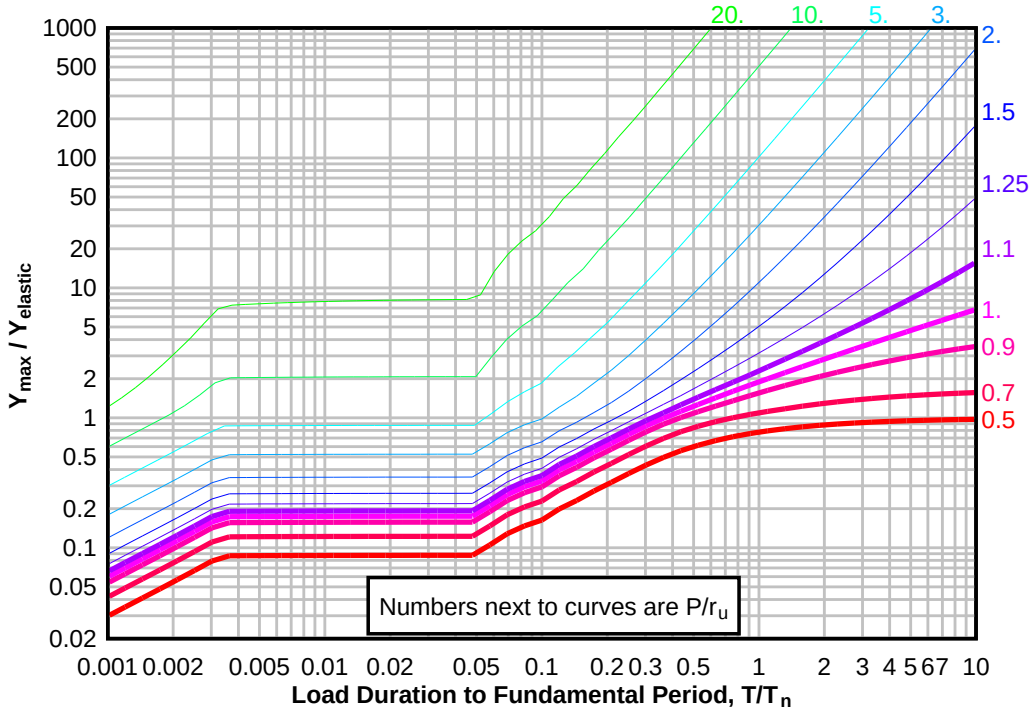


Figure 3-216(c) Maximum Response of Elasto-Plastic, One-Degree-of Freedom System for Bilinear-Triangular Pulse (C1 = 0.018, C2 = 300)

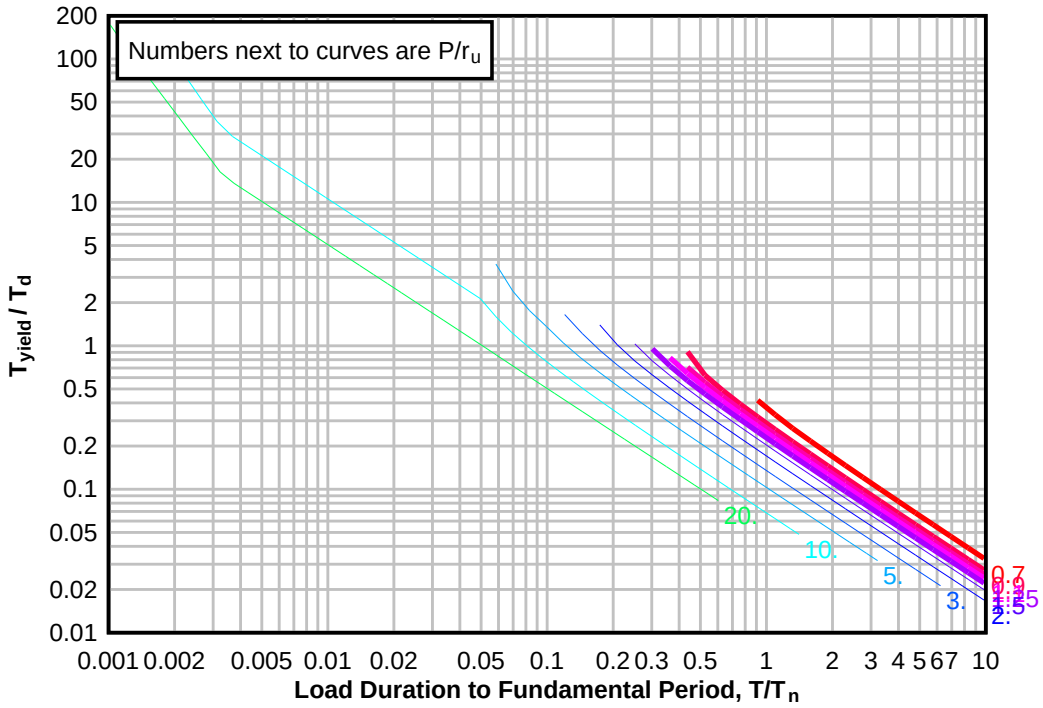


Figure 3-217(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.015, C_2 = 300)

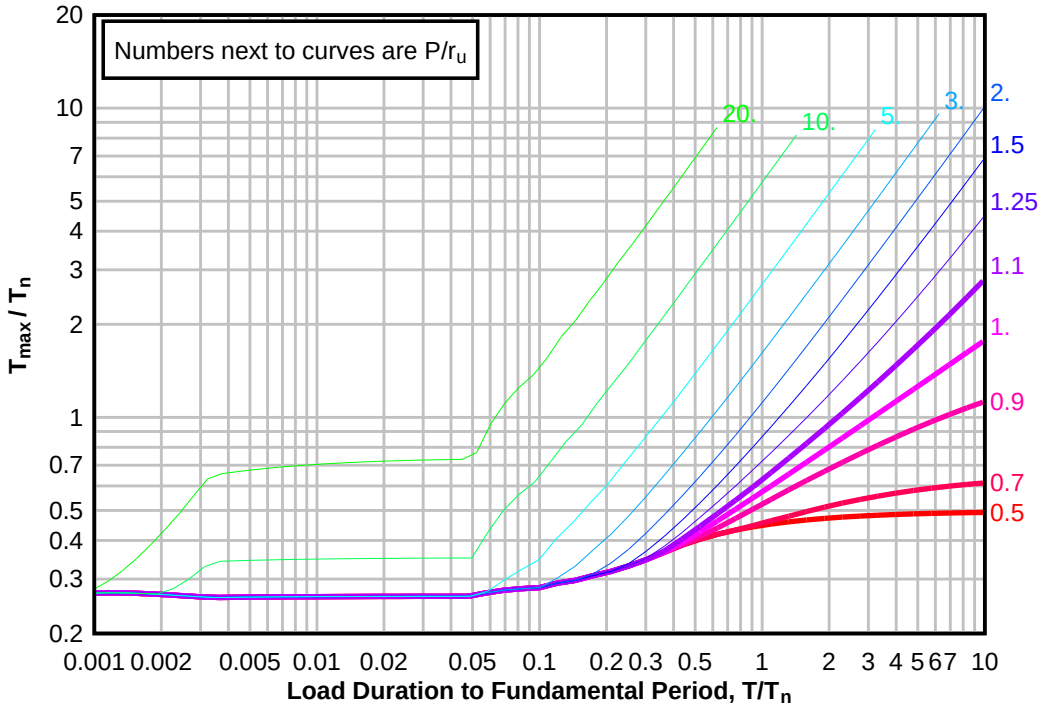


Figure 3-217(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.015, C2 = 300)

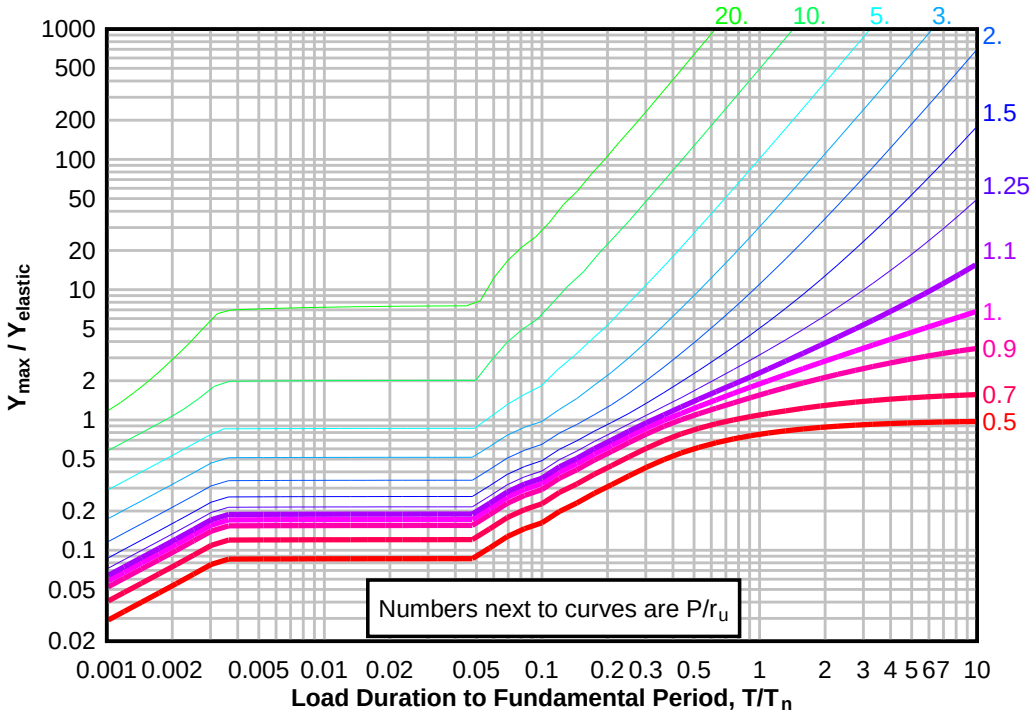


Figure 3-217(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.015, C2 = 300)

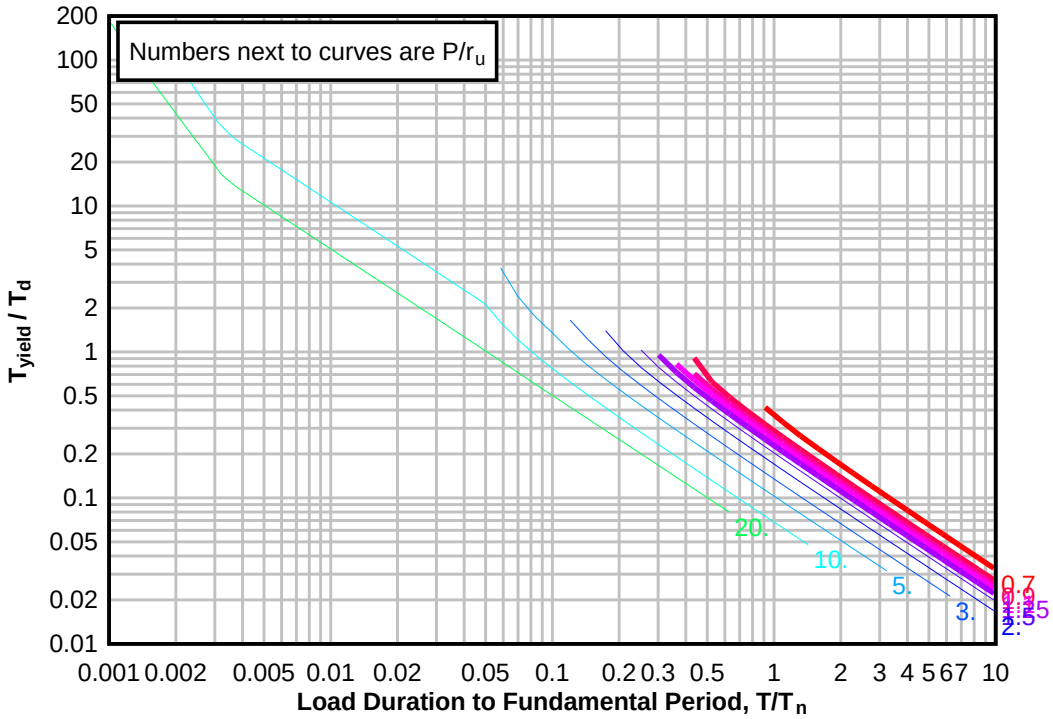


Figure 3-218(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.013, C_2 = 300)

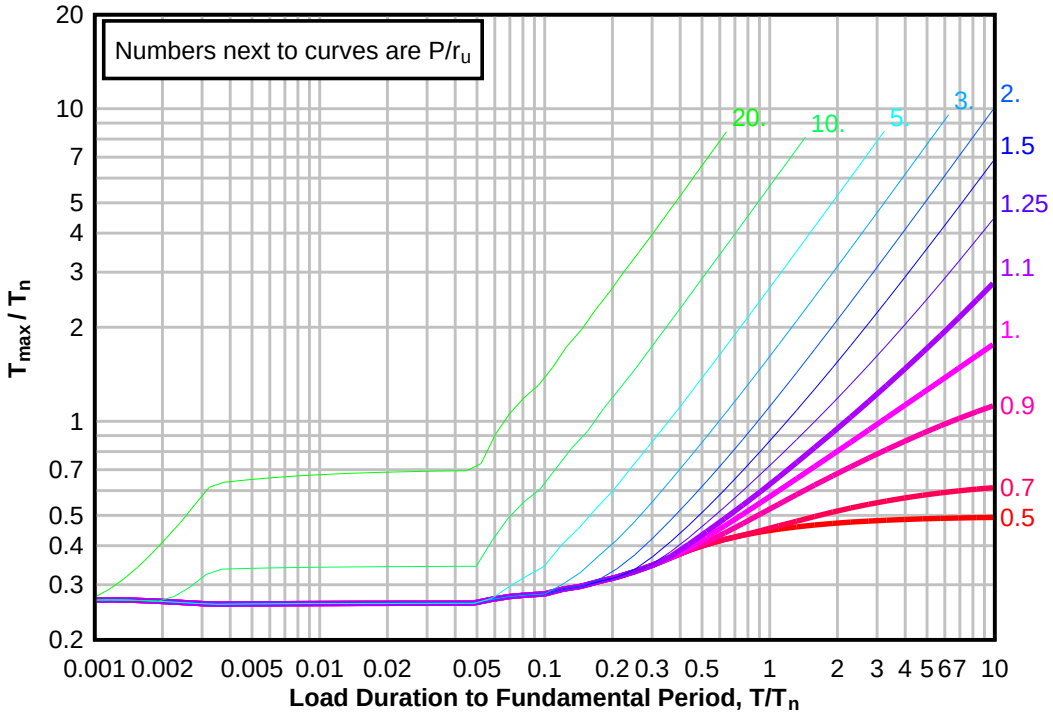


Figure 3-218(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.013, C2 = 300)

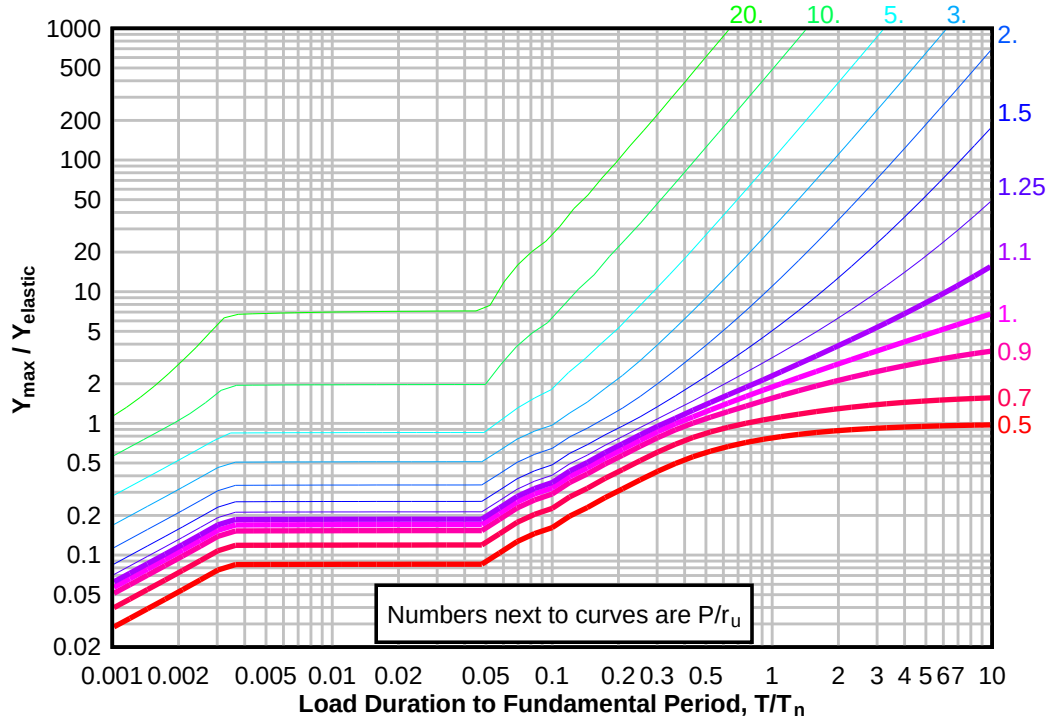


Figure 3-218(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.013, C2 = 300)

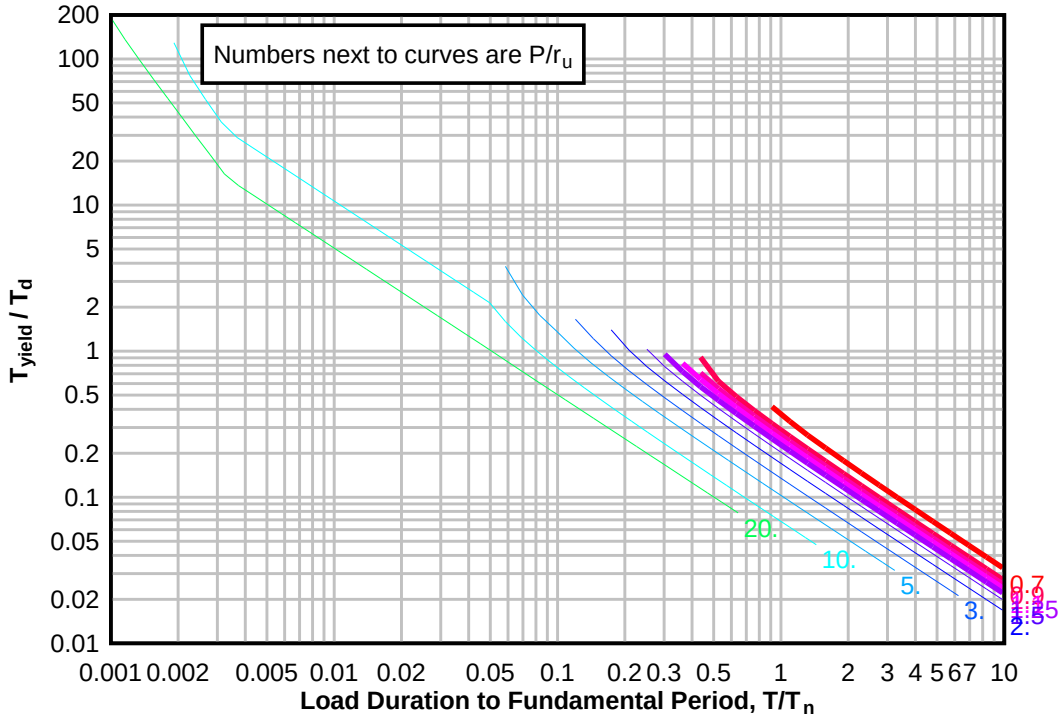


Figure 3-219(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.010, C_2 = 300)

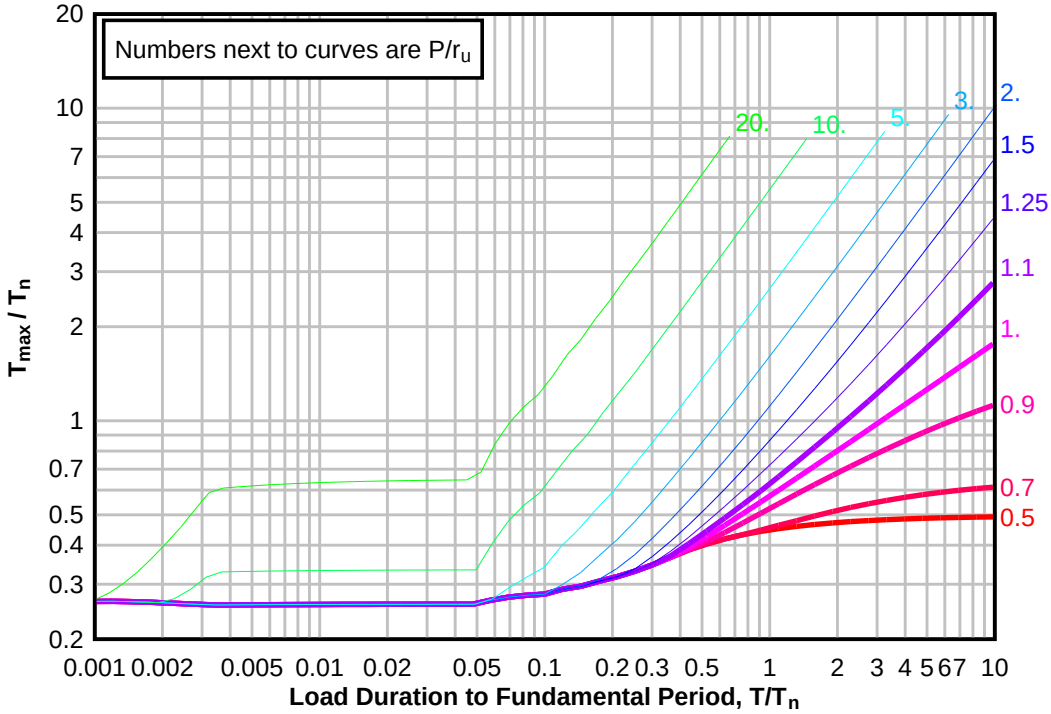


Figure 3-219(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.010, C2 = 300)

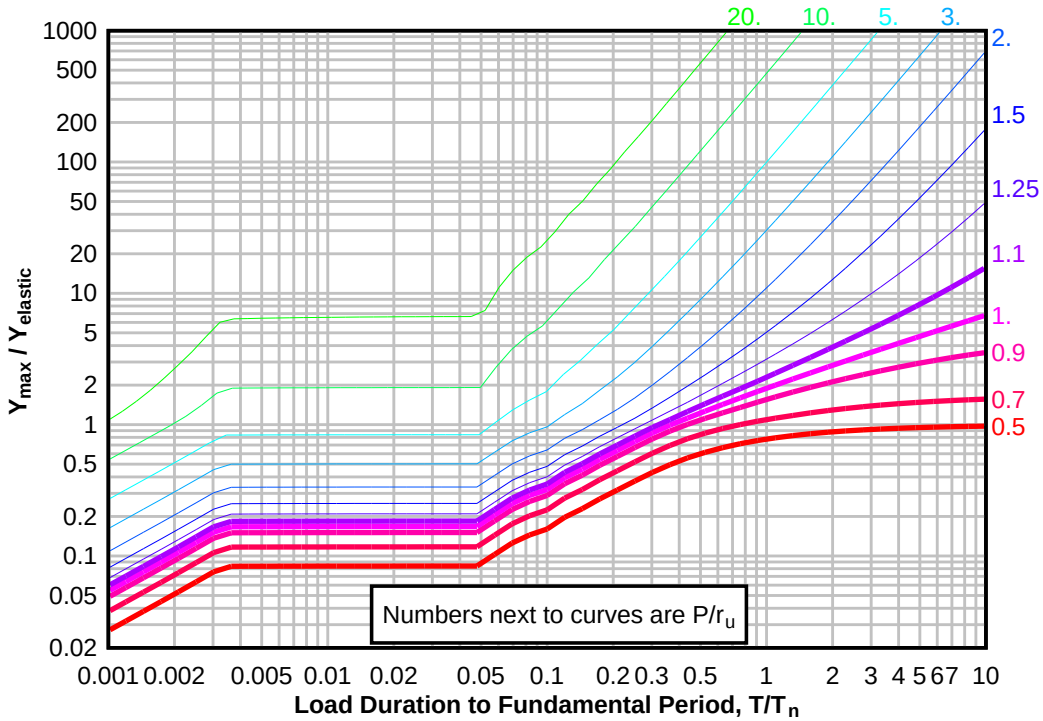


Figure 3-219(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.010, C2 = 300)

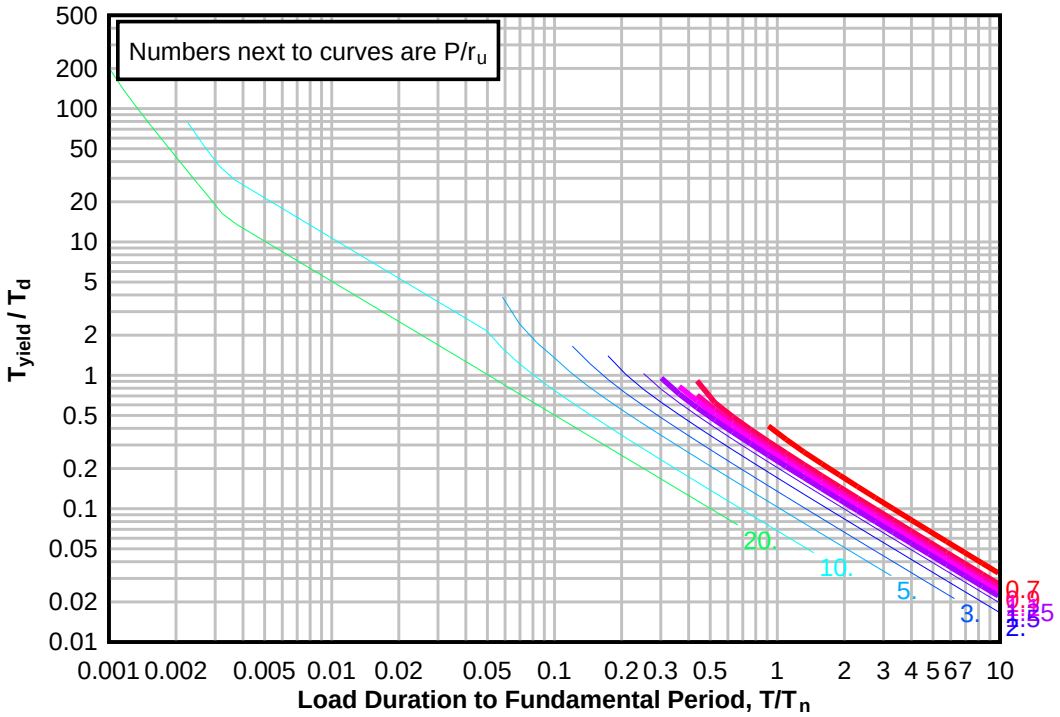


Figure 3-220 Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.909, C_2 = 1000)

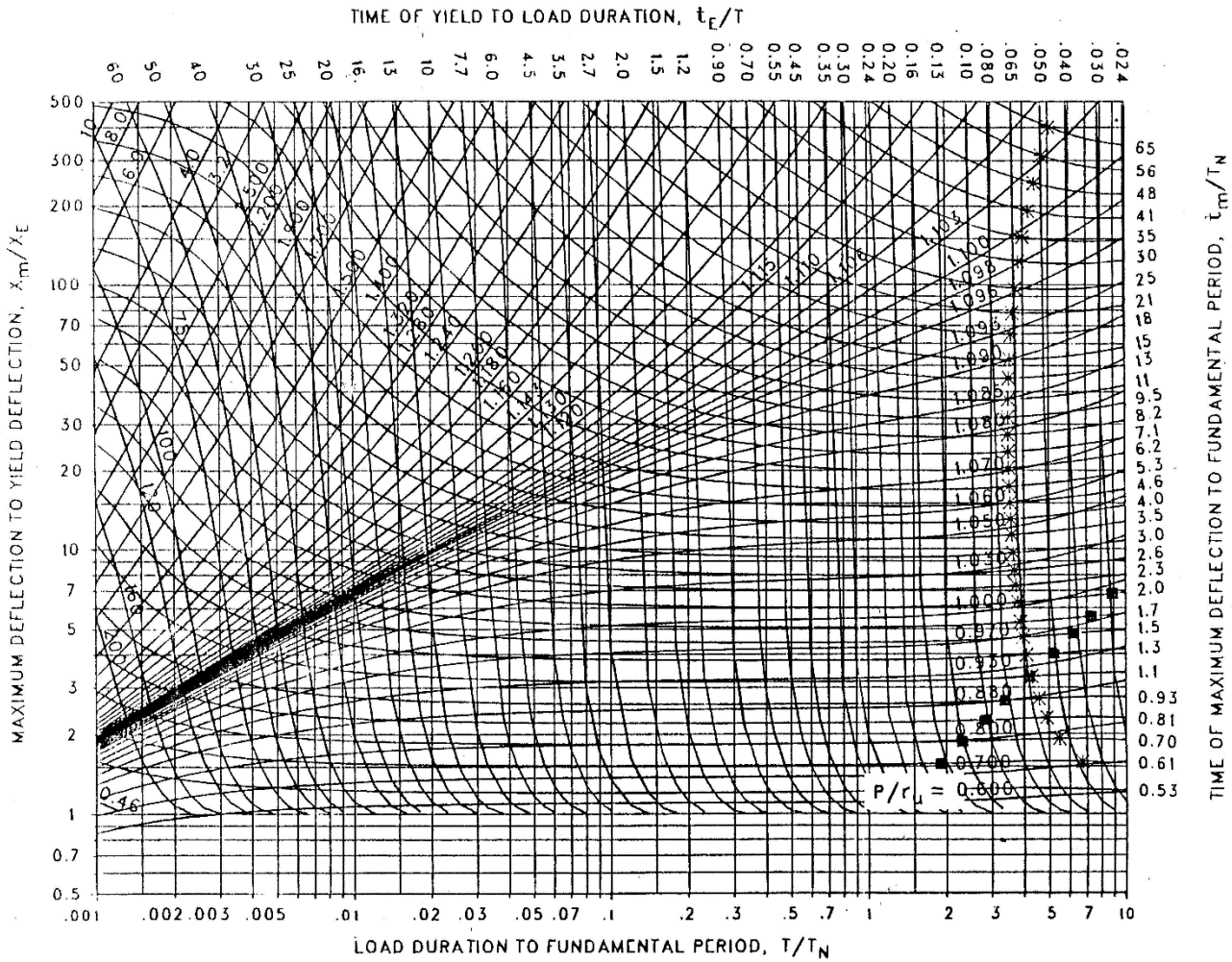


Figure 3-220 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.909, C_2 = 1000.)

Figure 3-221 Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.866, C_2 = 1000)

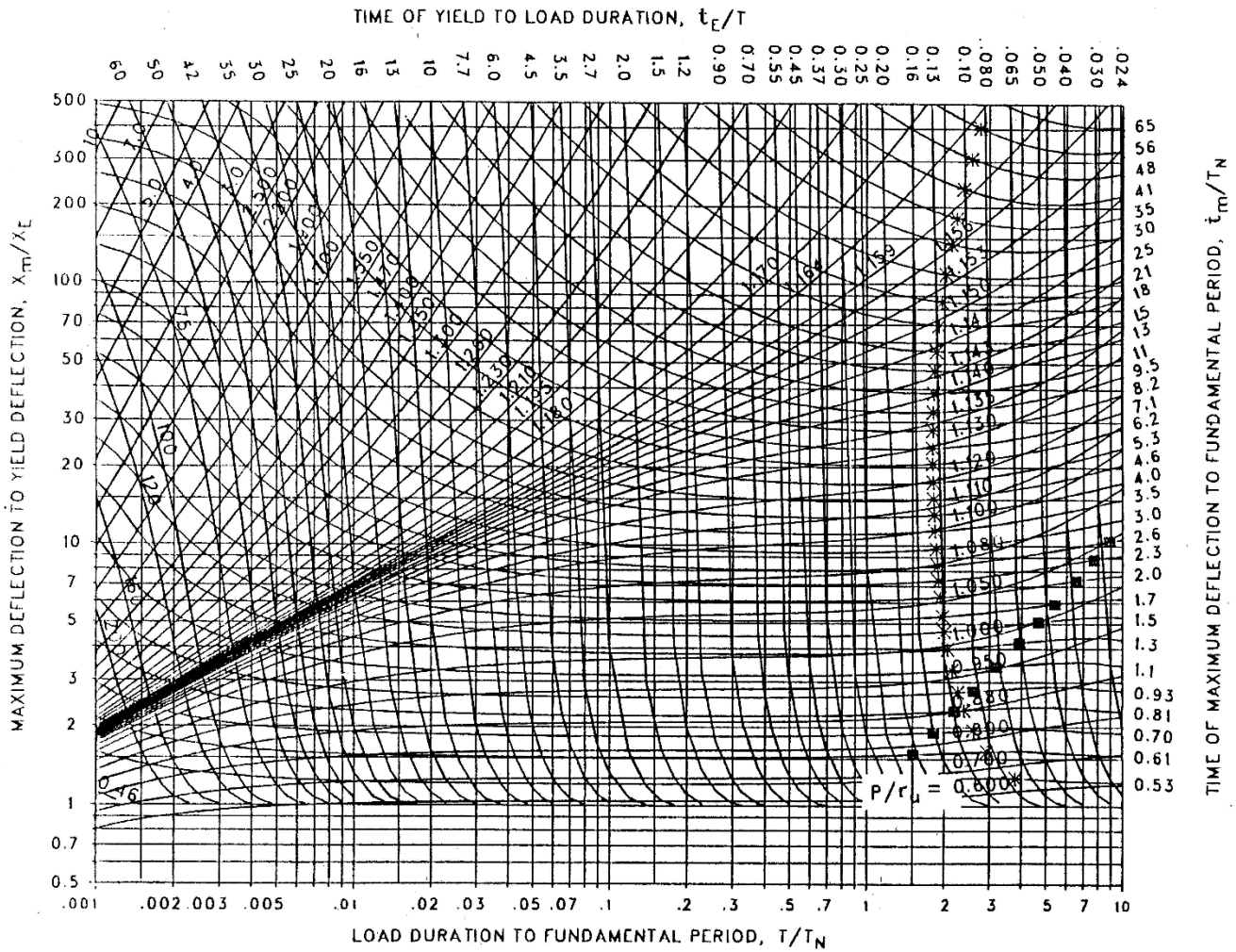


Figure 3-221 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.866, C_2 = 1000.)

Figure 3-222 Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.825, C_2 = 1000)

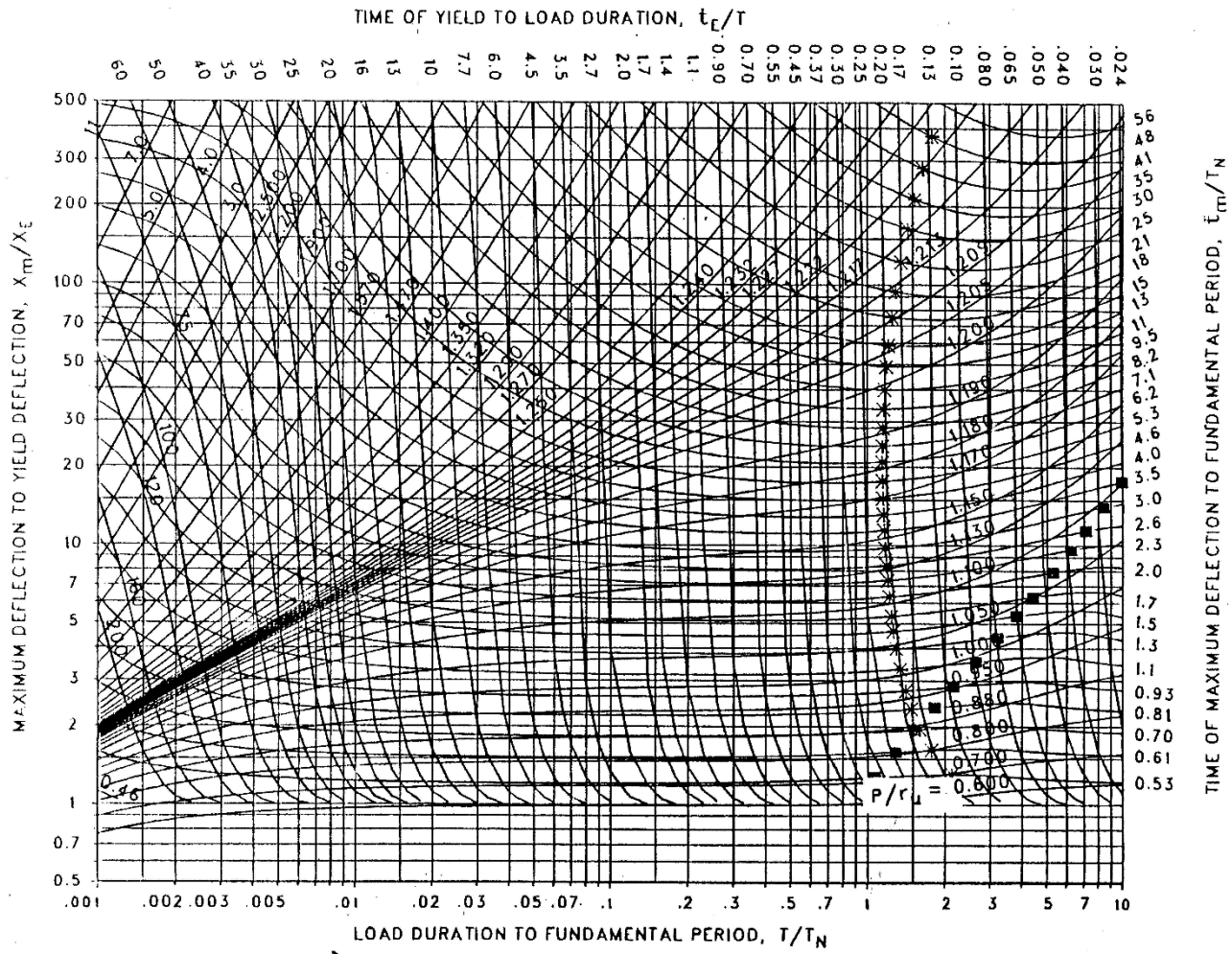


Figure 3-222 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.825, C_2 = 1000.)

Figure 3-223 Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.787, C_2 = 1000)

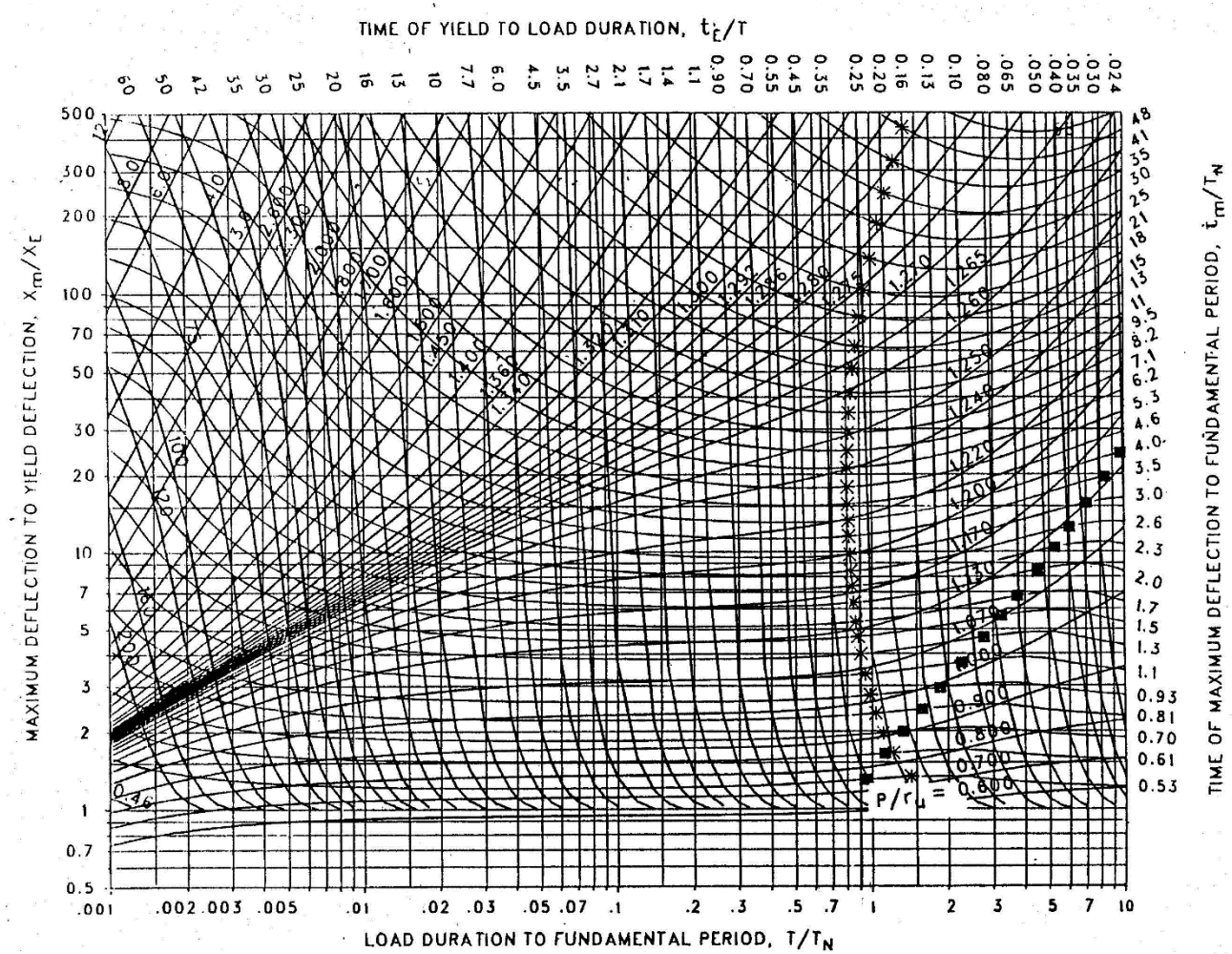


Figure 3-223 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.787, C_2 = 1000.)

Figure 3-224 Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.750, C_2 = 1000)

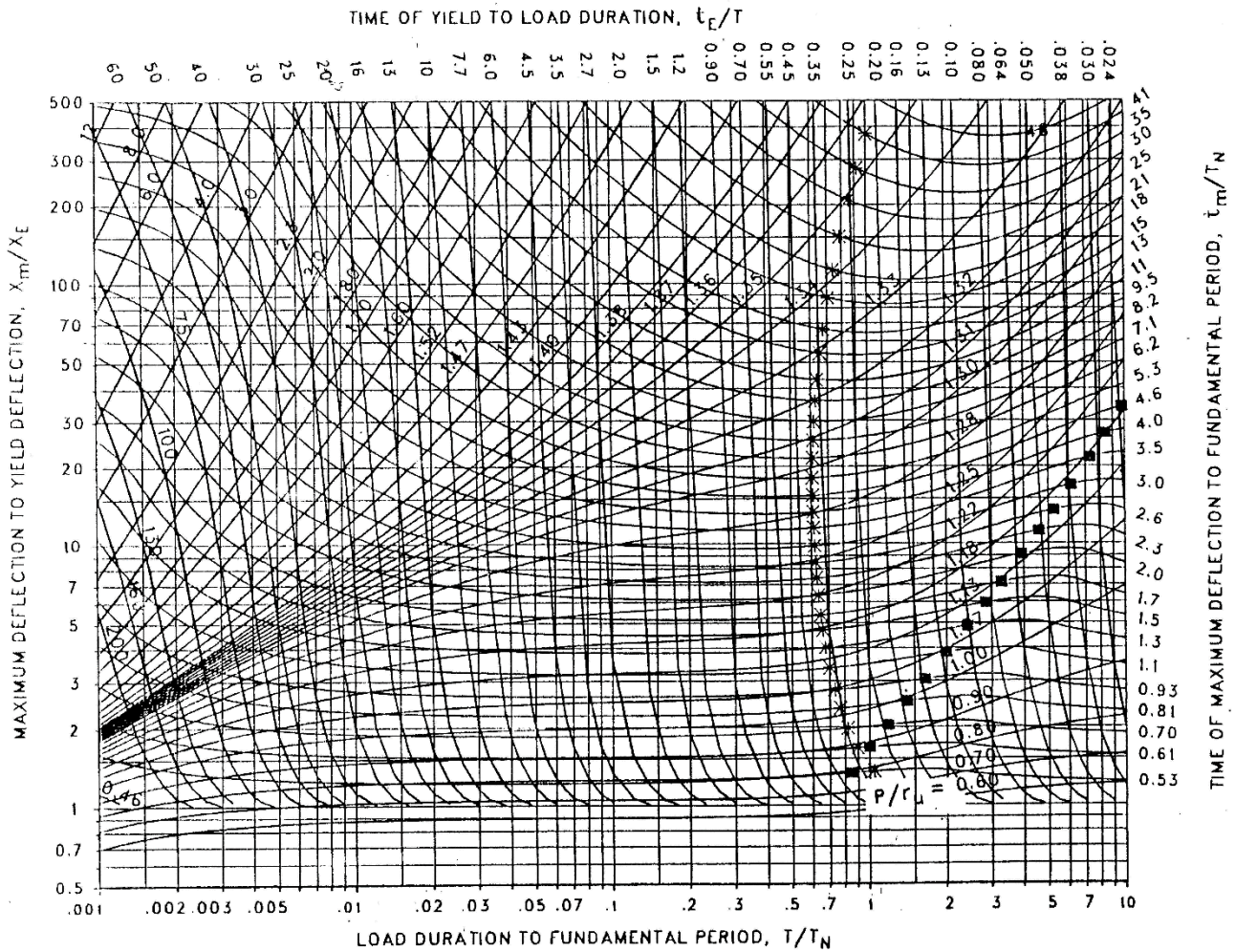


Figure 3-224 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.750, C_2 = 1000.)

Figure 3-225(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.715, C_2 = 1000)

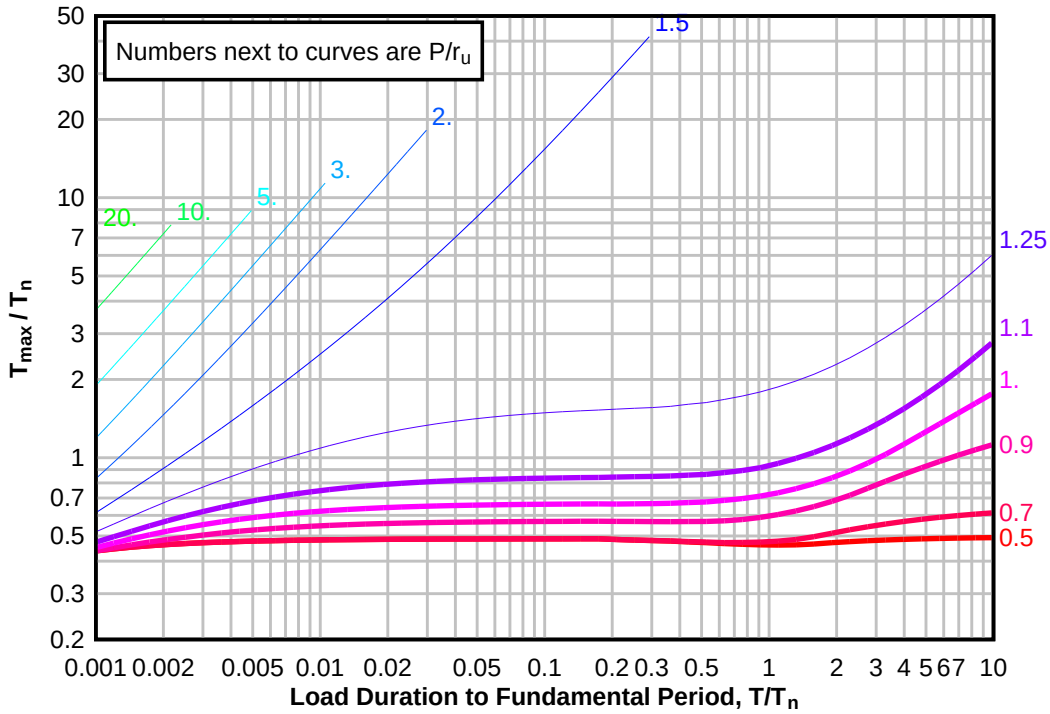


Figure 3-225(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.715, C2 = 1000)

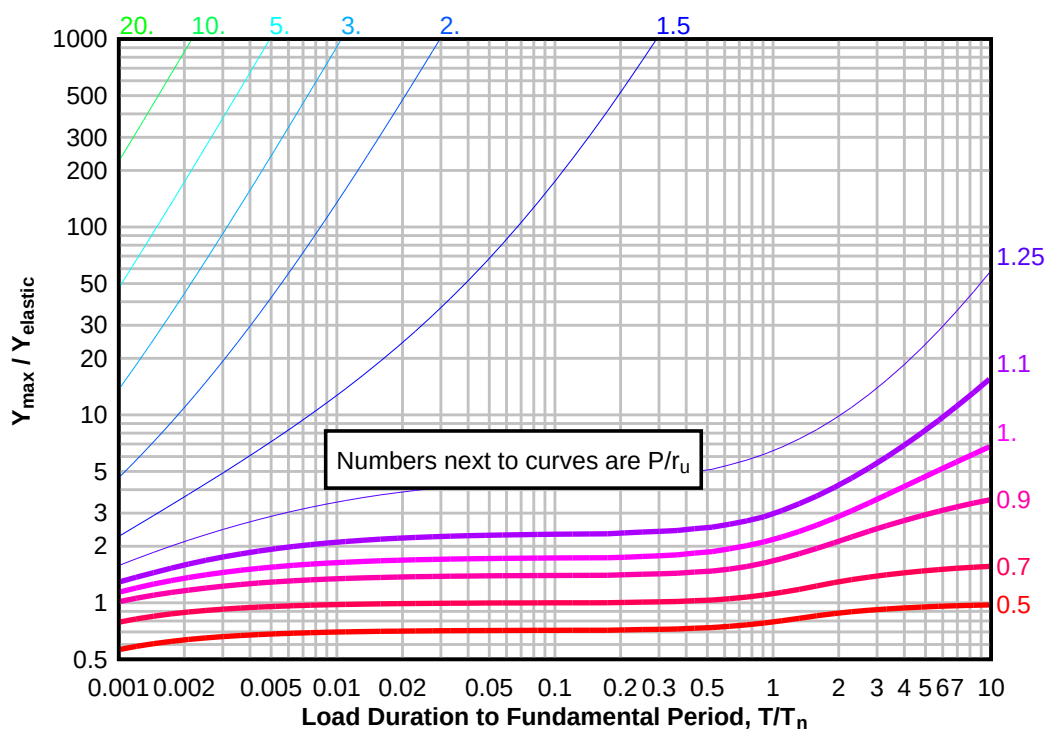


Figure 3-225(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.715, C2 = 1000)

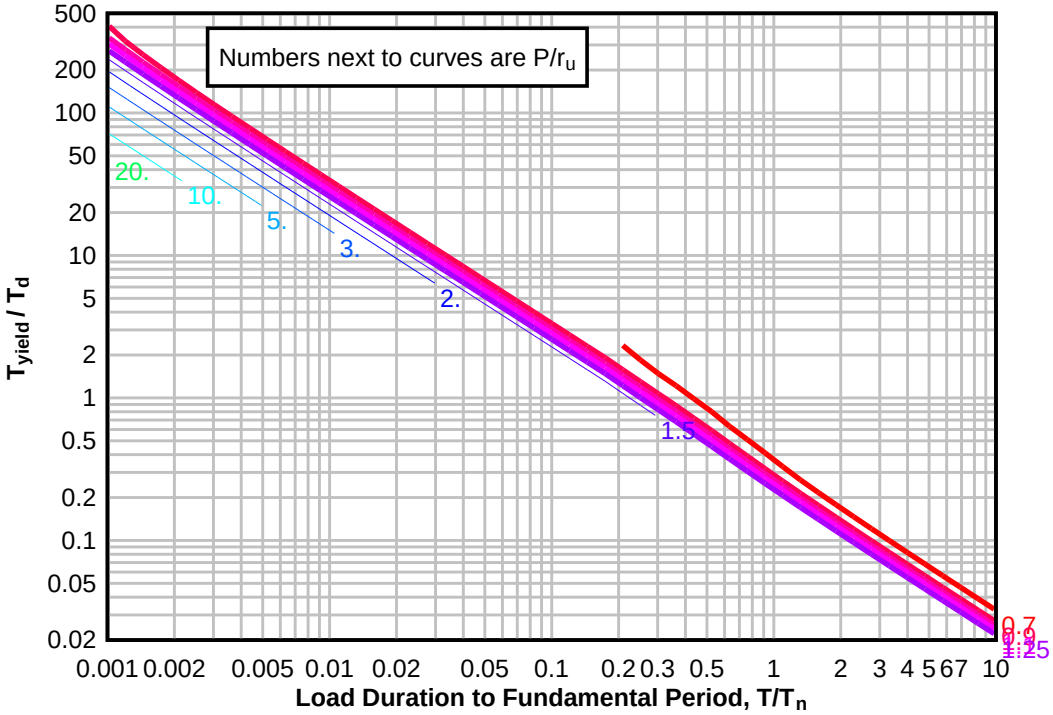


Figure 3-226(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.681, C_2 = 1000)

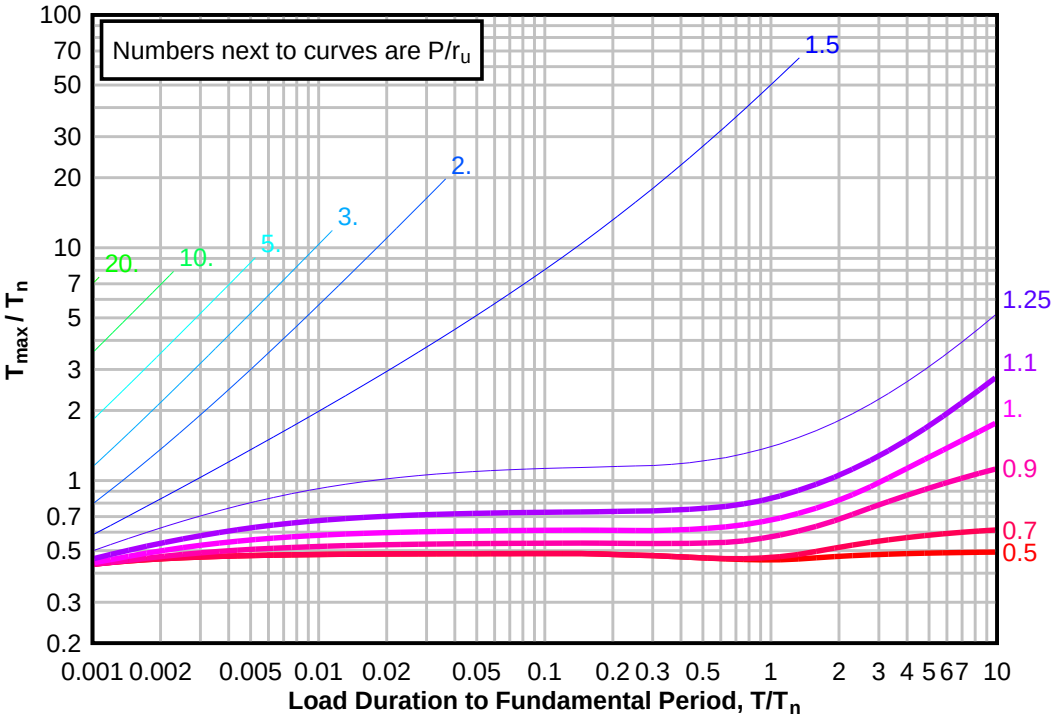


Figure 3-226(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.681, C2 = 1000)

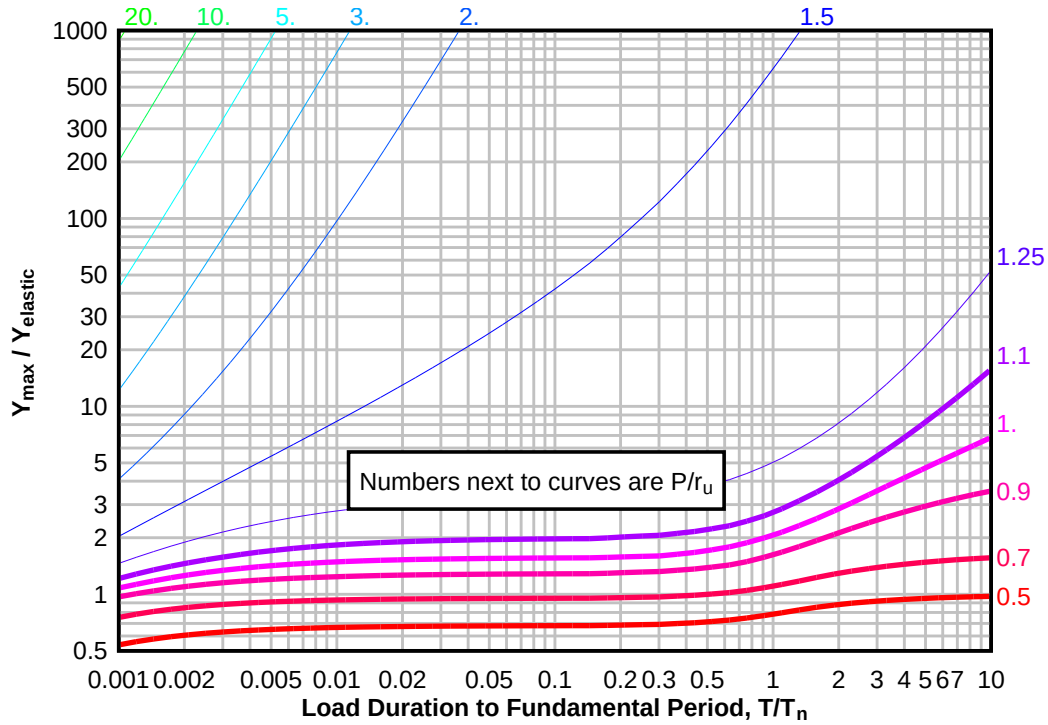


Figure 3-226(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.681, C2 = 1000)

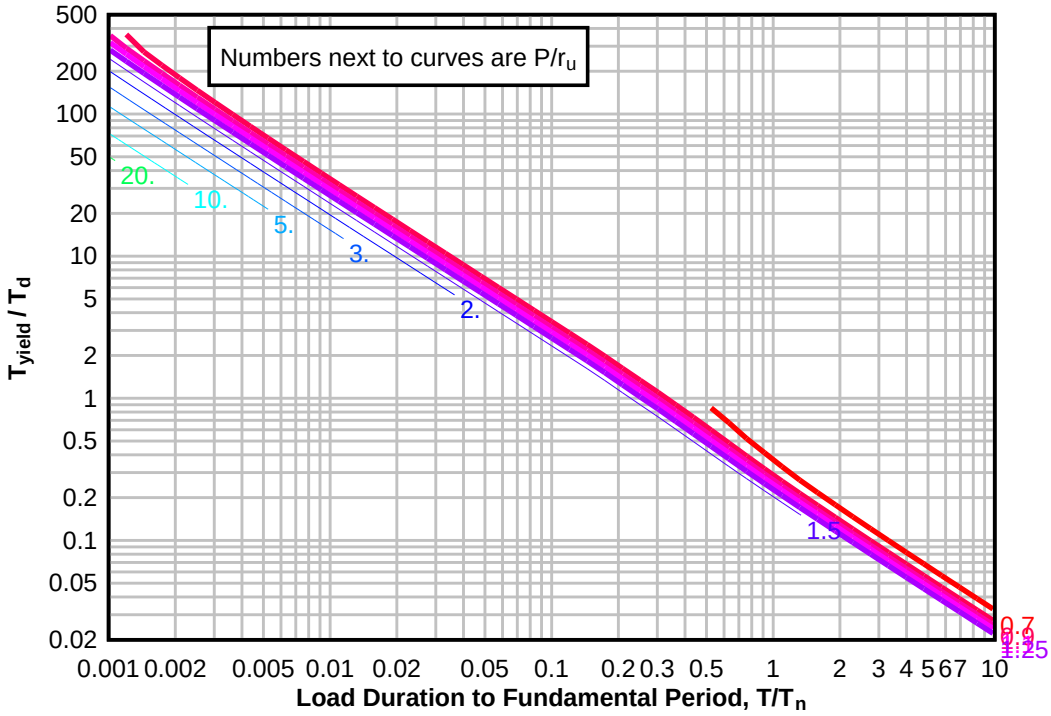


Figure 3-227(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.648, C_2 = 1000)

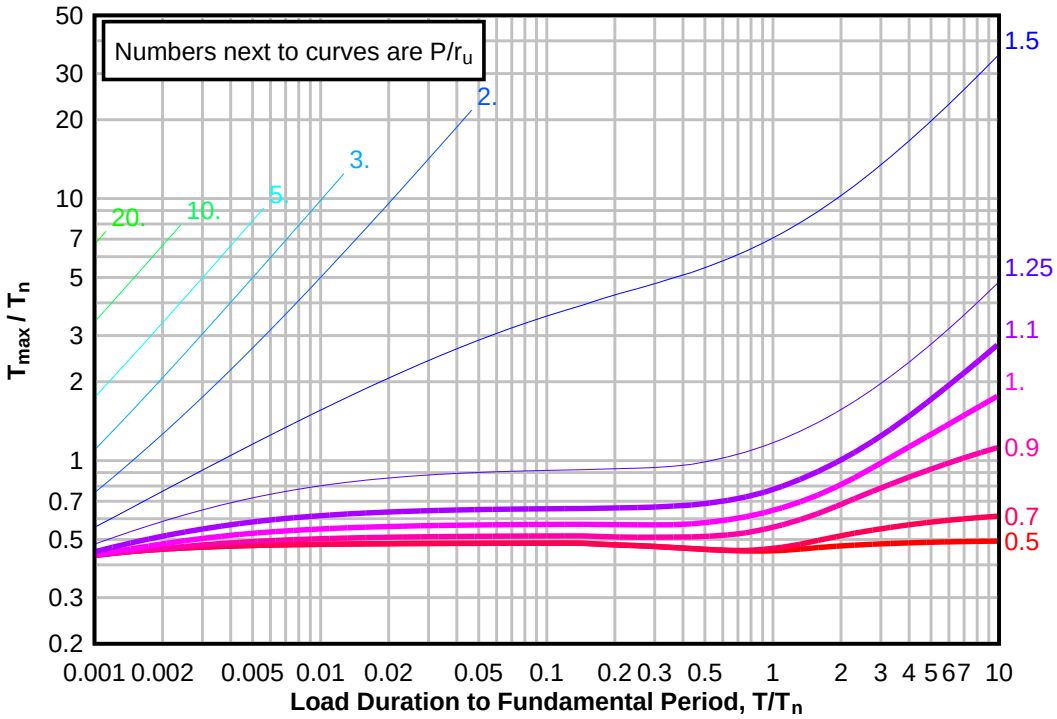


Figure 3-227(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.648, C2 = 1000)

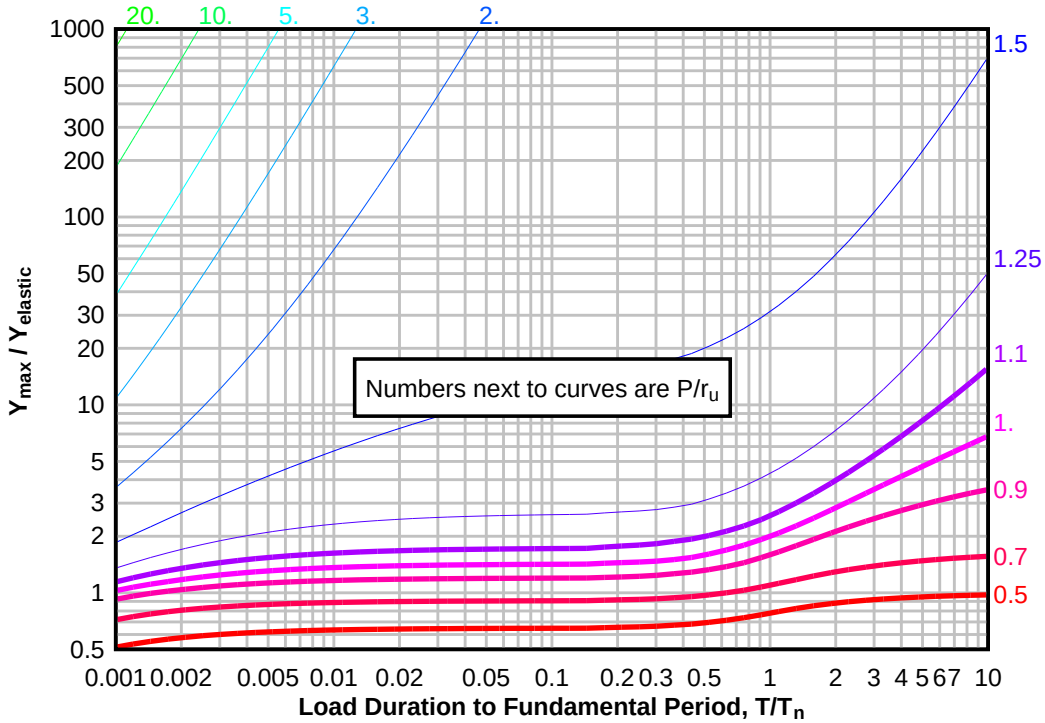


Figure 3-227(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.648, C2 = 1000)

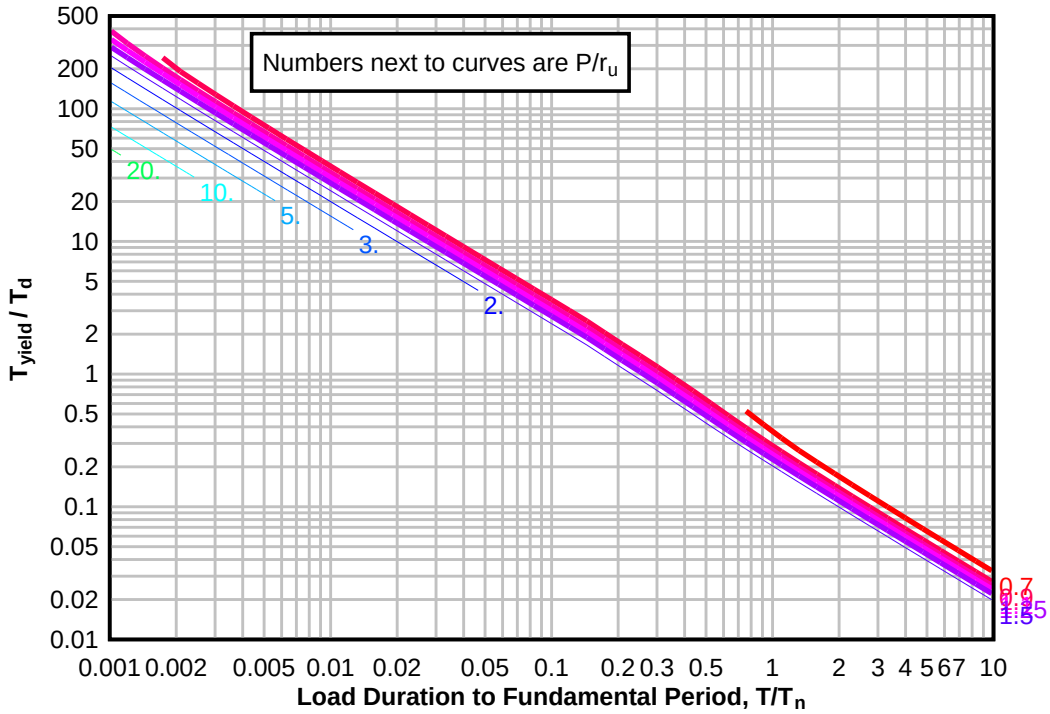


Figure 3-228(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.619, C_2 = 1000)

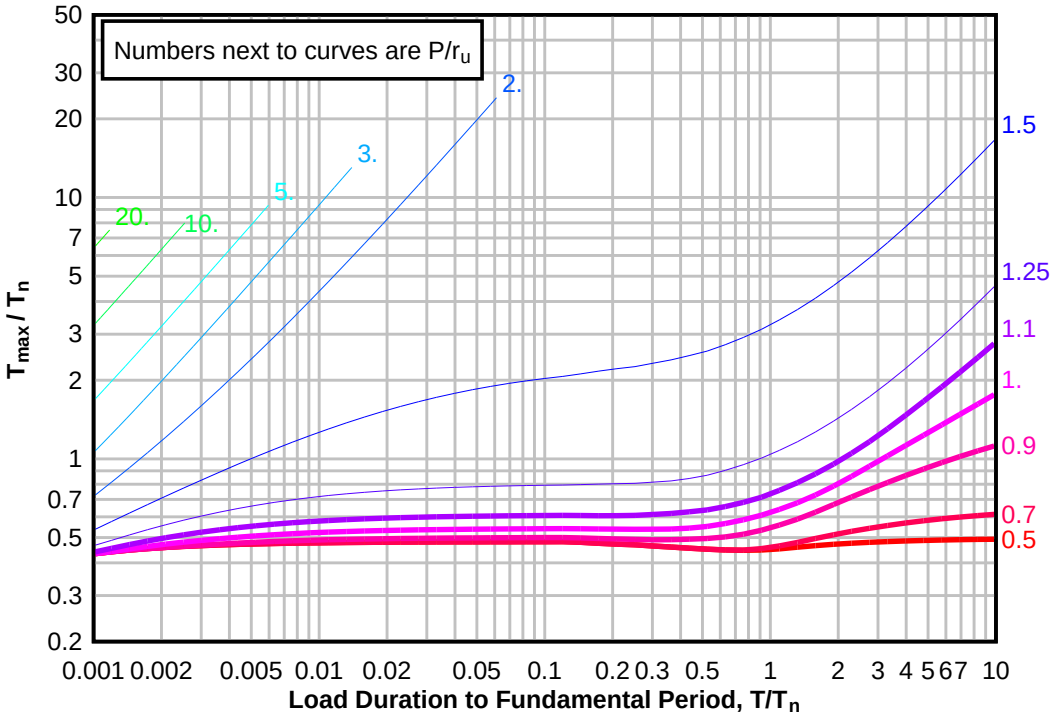


Figure 3-228(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.619, C2 = 1000)

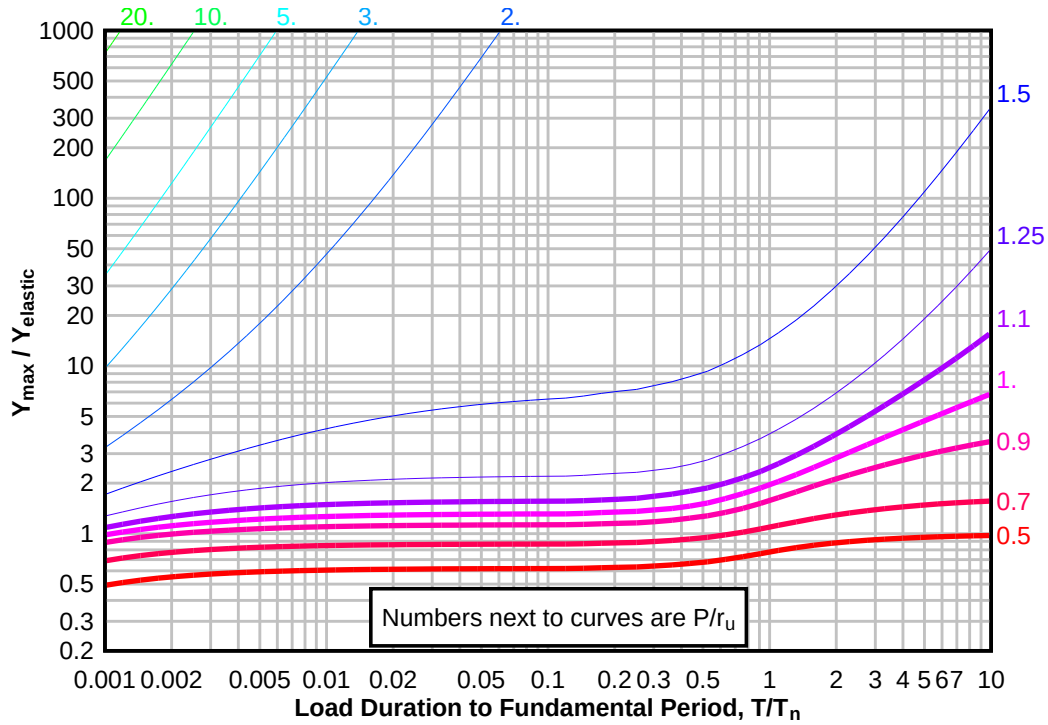


Figure 3-228(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.619, C2 = 1000)

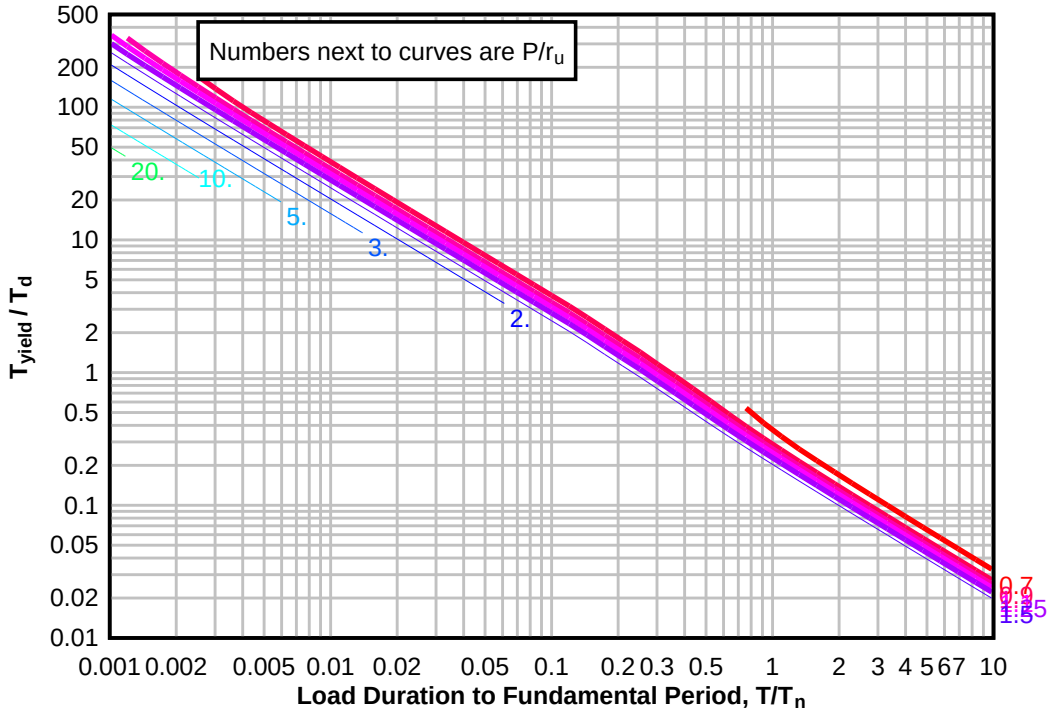


Figure 3-229(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.590, C_2 = 1000)

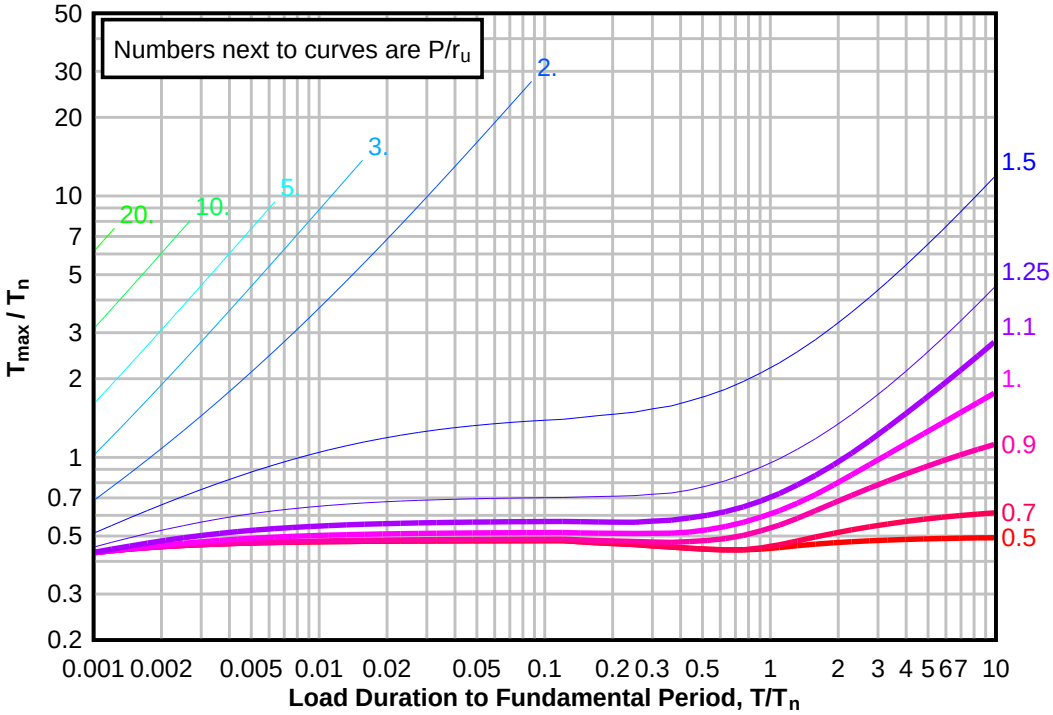


Figure 3-229(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.590, C2 = 1000)

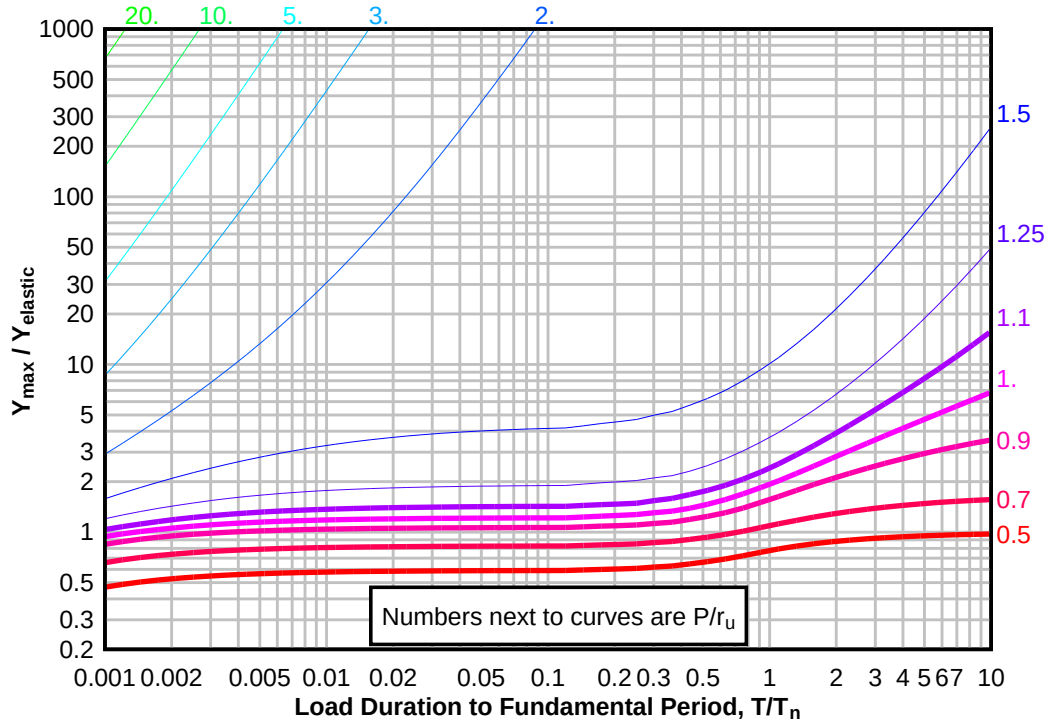


Figure 3-229(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.590, C2 = 1000)

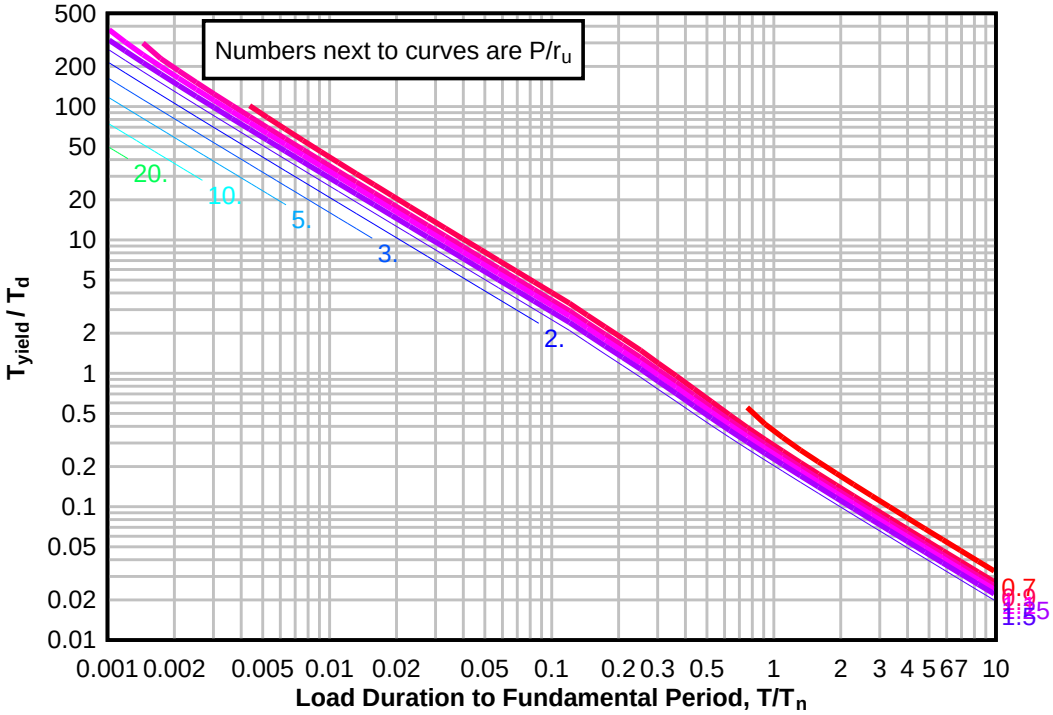


Figure 3-230(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.562, C_2 = 1000)

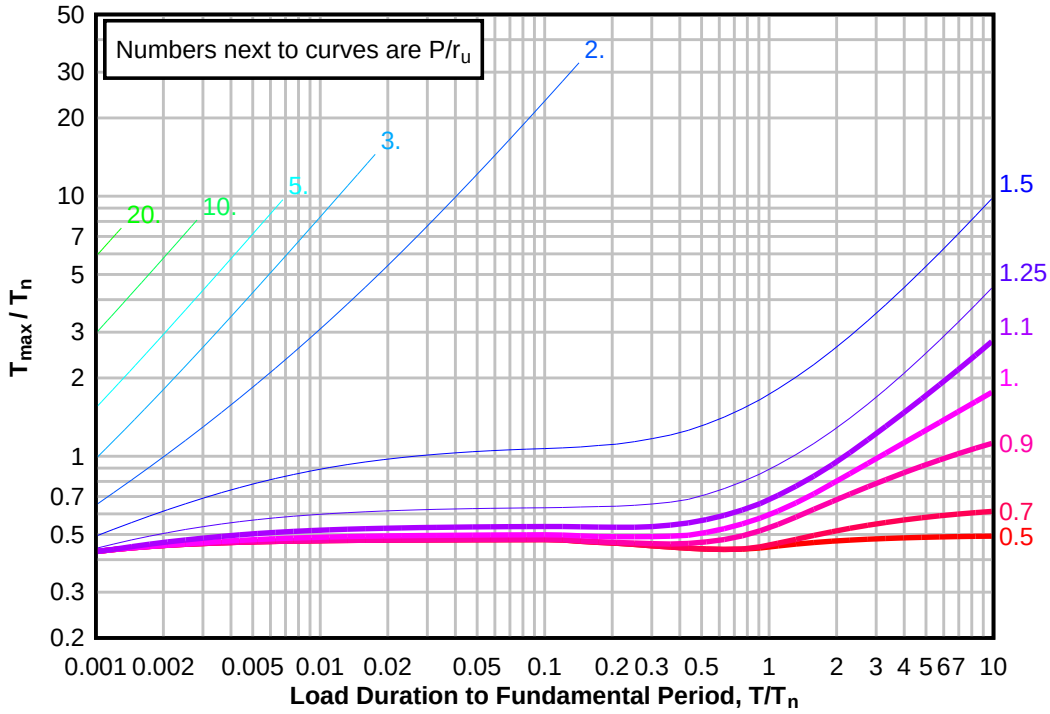


Figure 3-230(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.562, C2 = 1000)

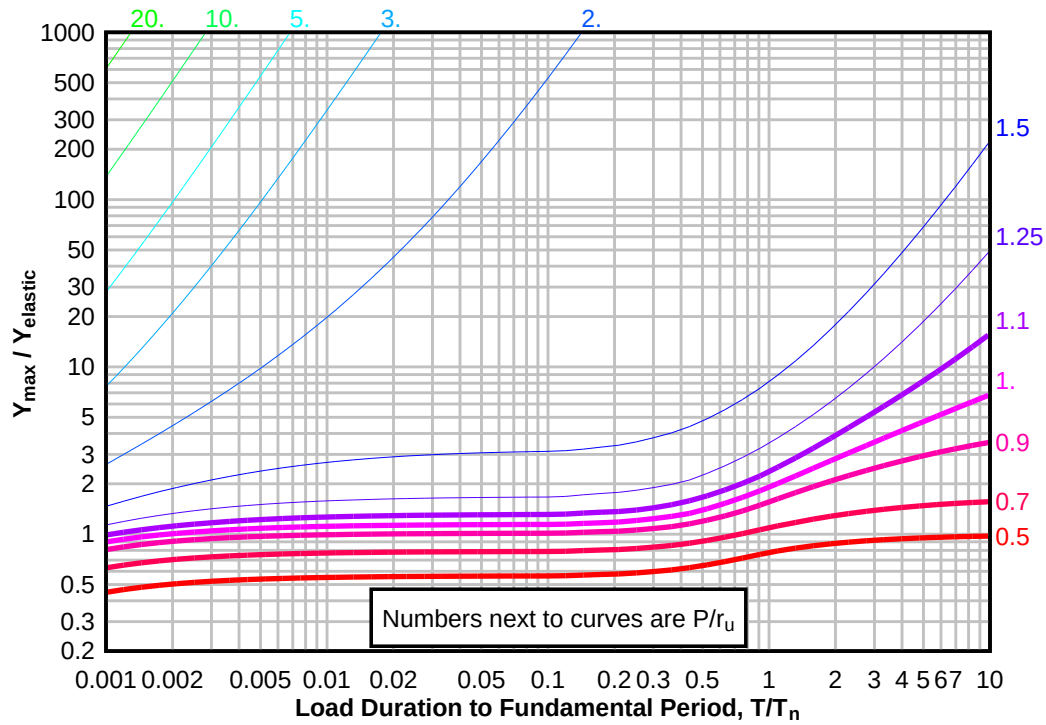


Figure 3-230(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.562, C2 = 1000)

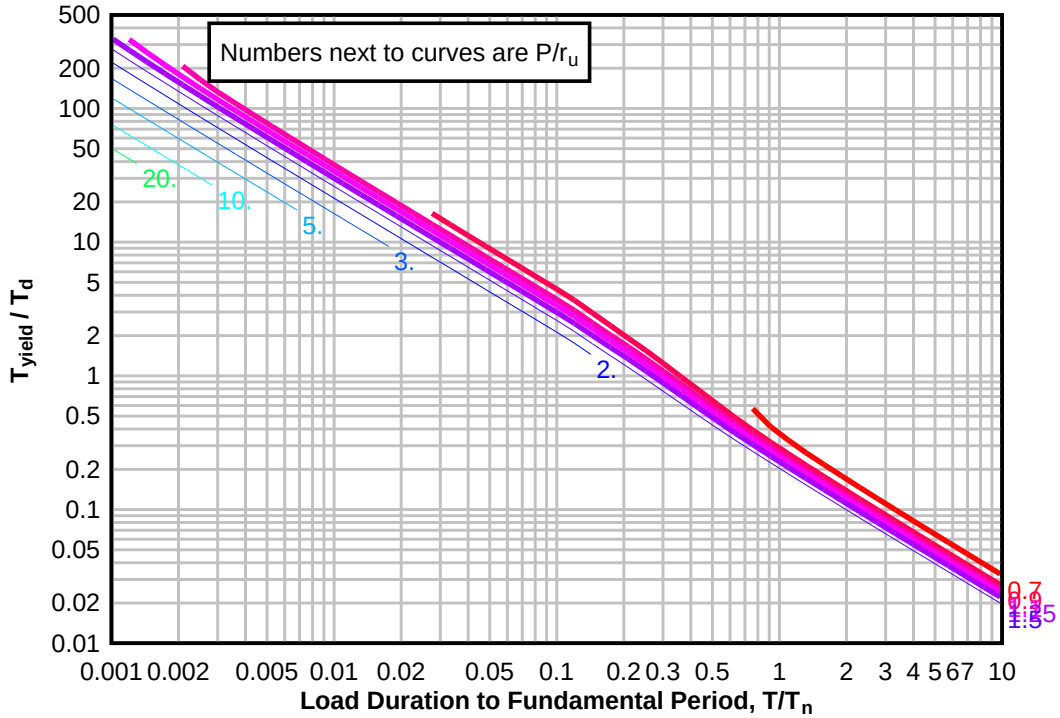


Figure 3-231(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.536, C_2 = 1000)

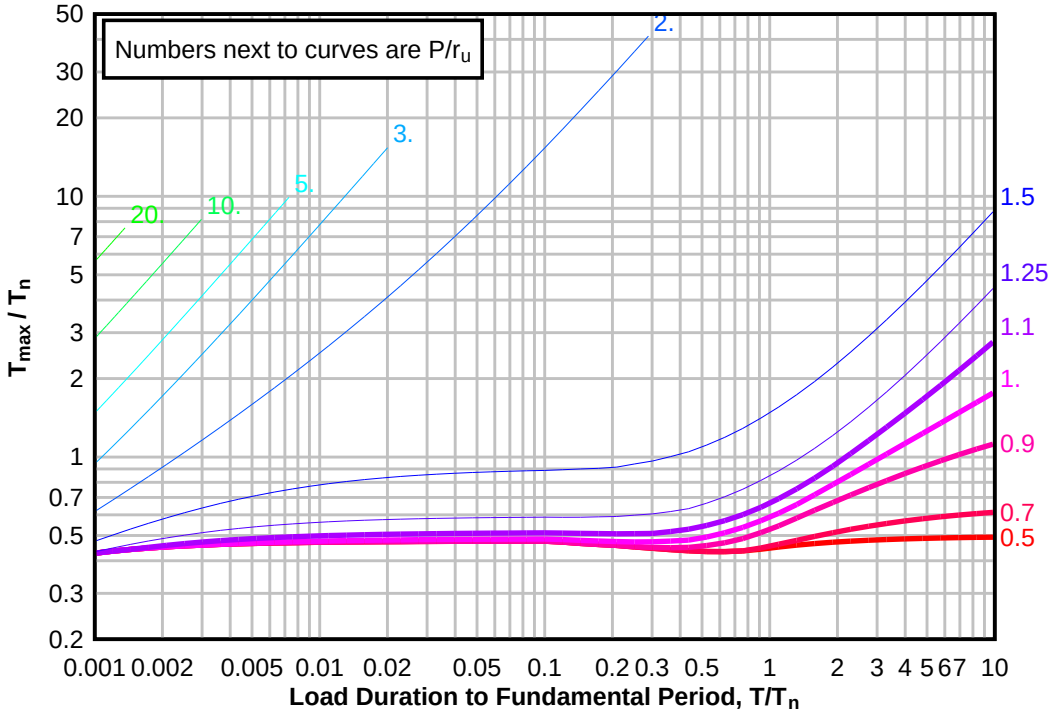


Figure 3-231(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.536, C2 = 1000)

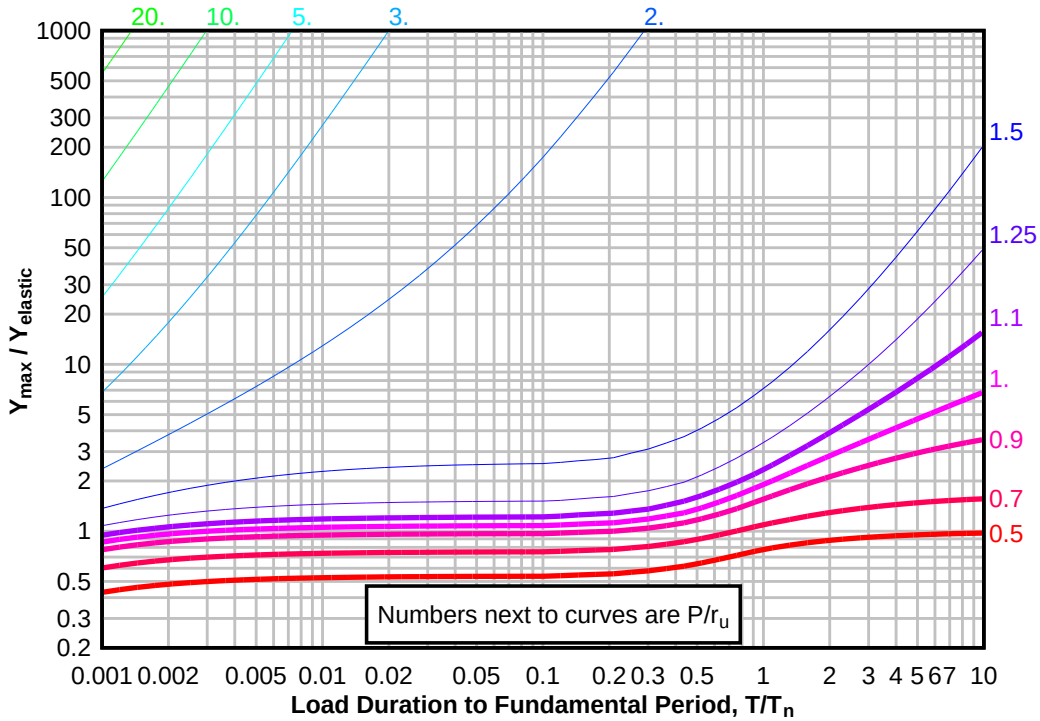


Figure 3-231(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.536, C2 = 1000)

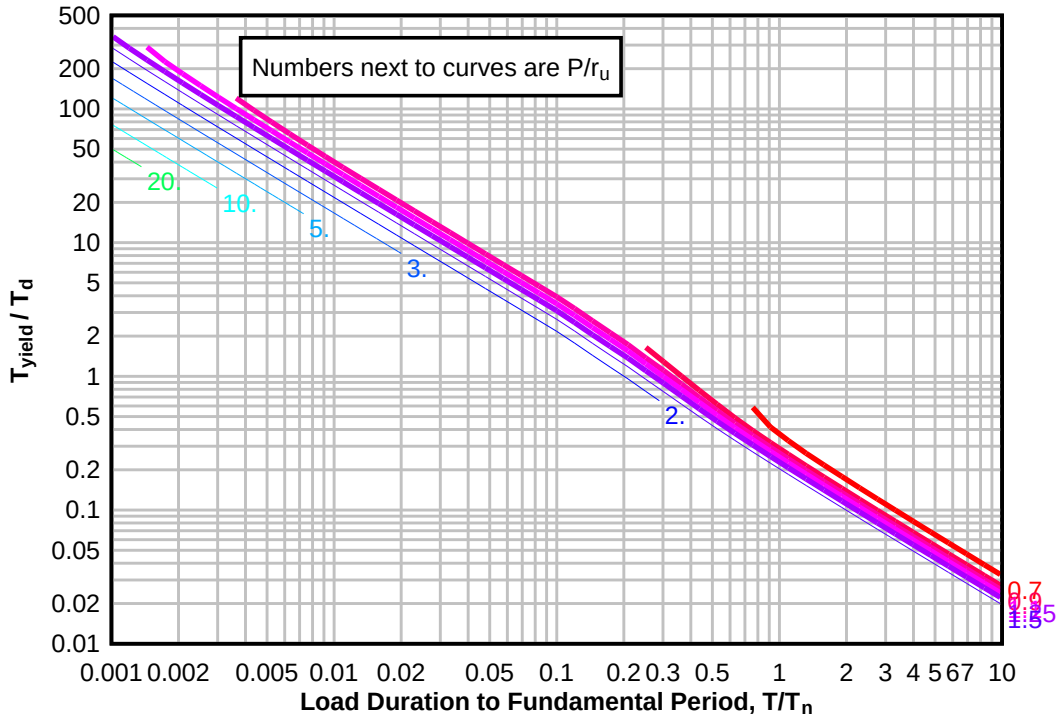


Figure 3-232(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.511, C_2 = 1000)

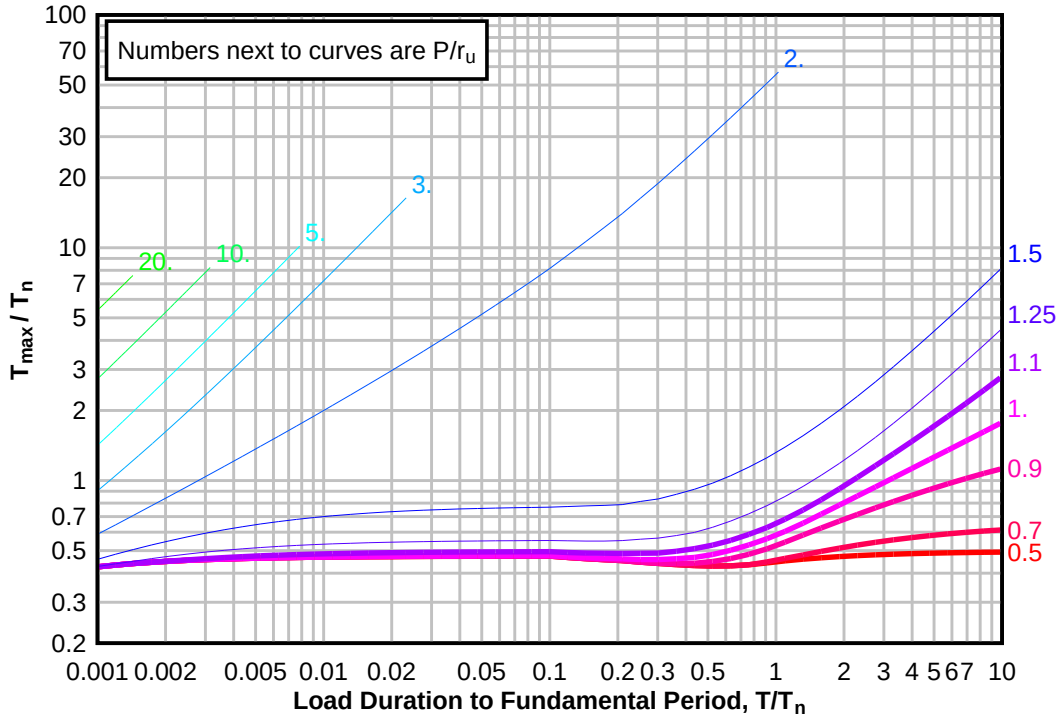


Figure 3-232(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.511, C2 = 1000)

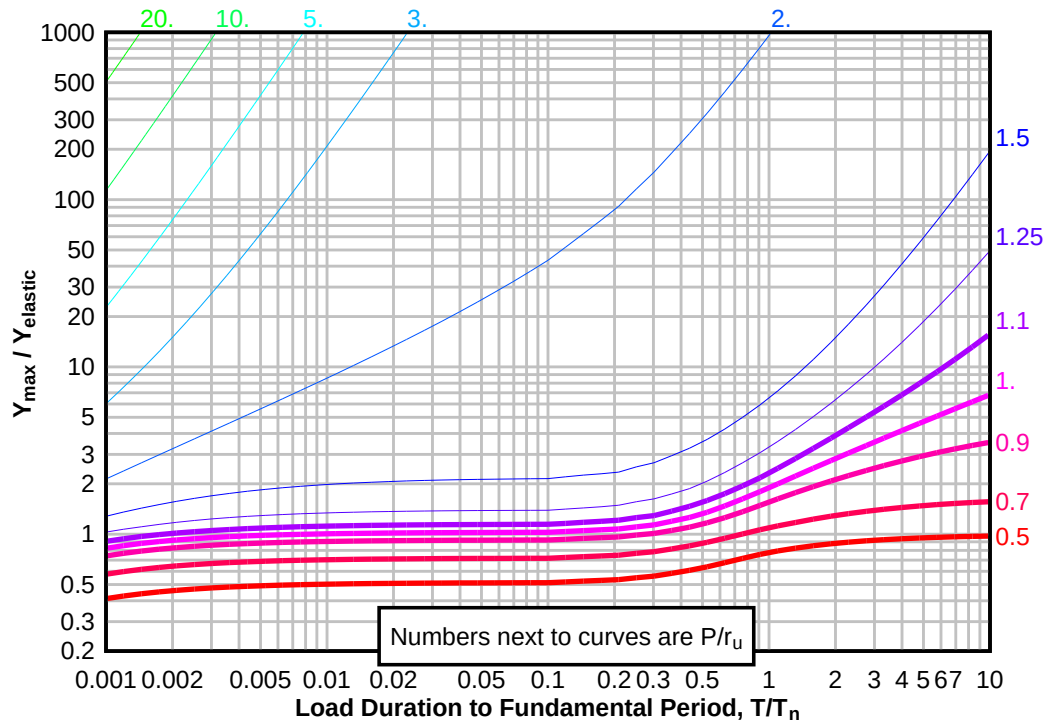


Figure 3-232(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.511, C2 = 1000)

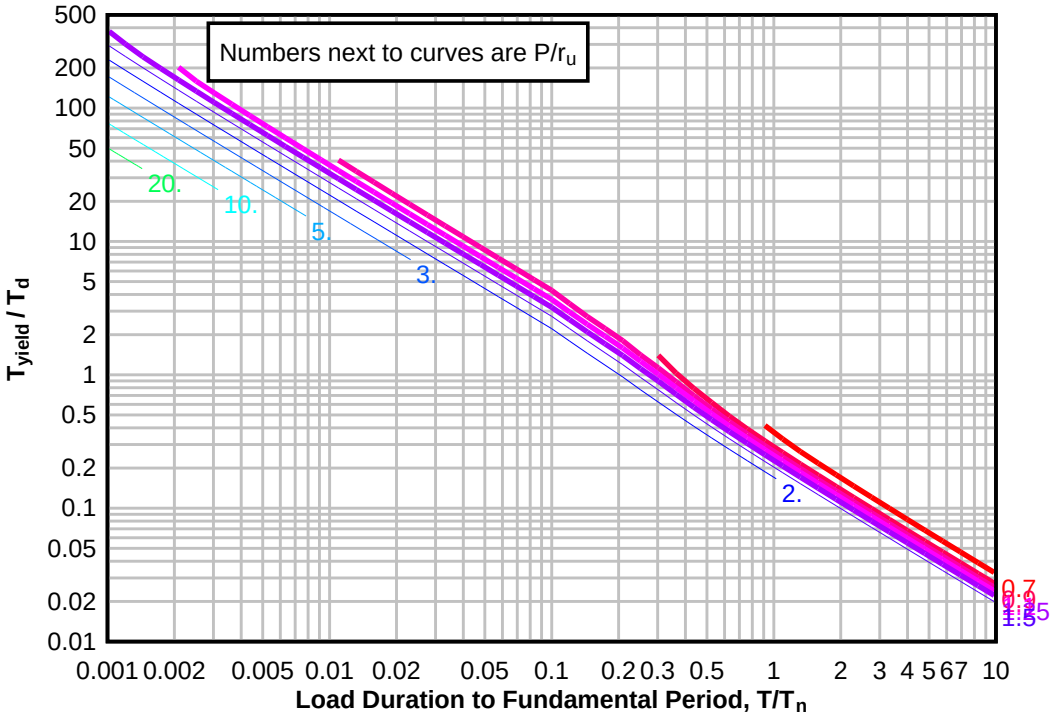


Figure 3-233(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.487, C_2 = 1000)

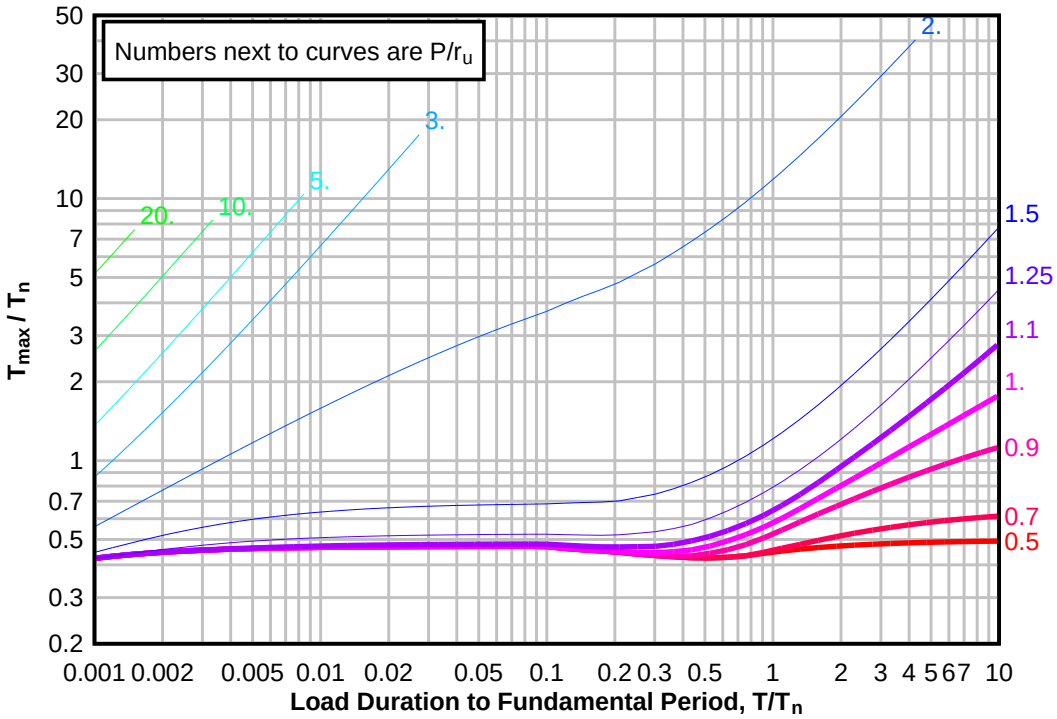


Figure 3-233(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.487, C2 = 1000)

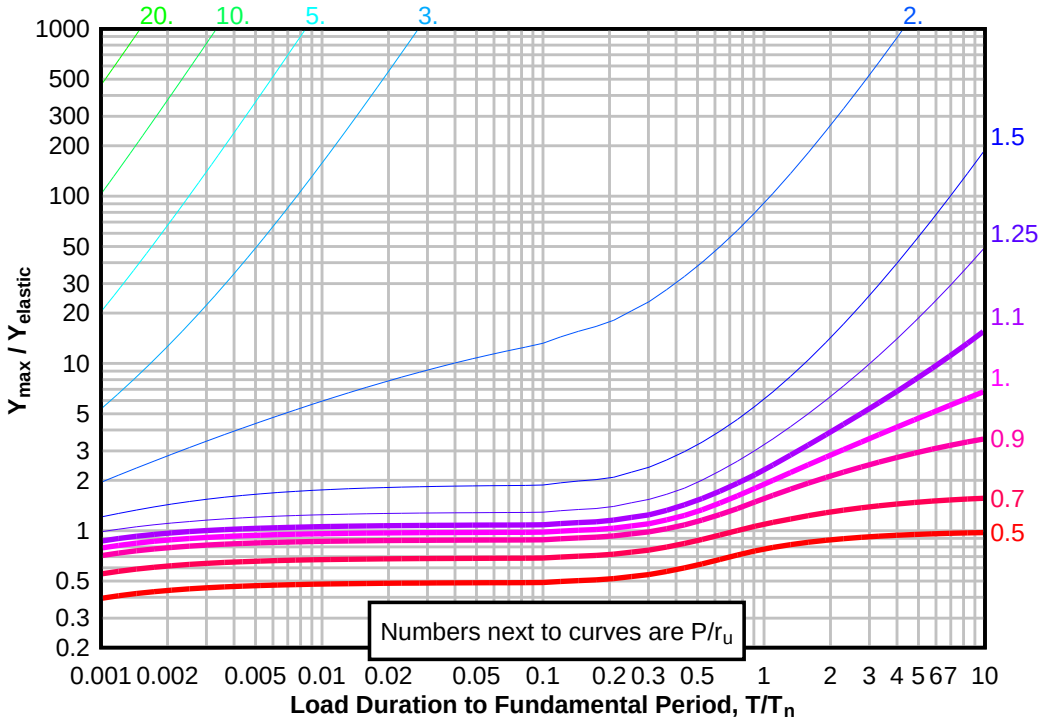


Figure 3-233(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.487, C2 = 1000)

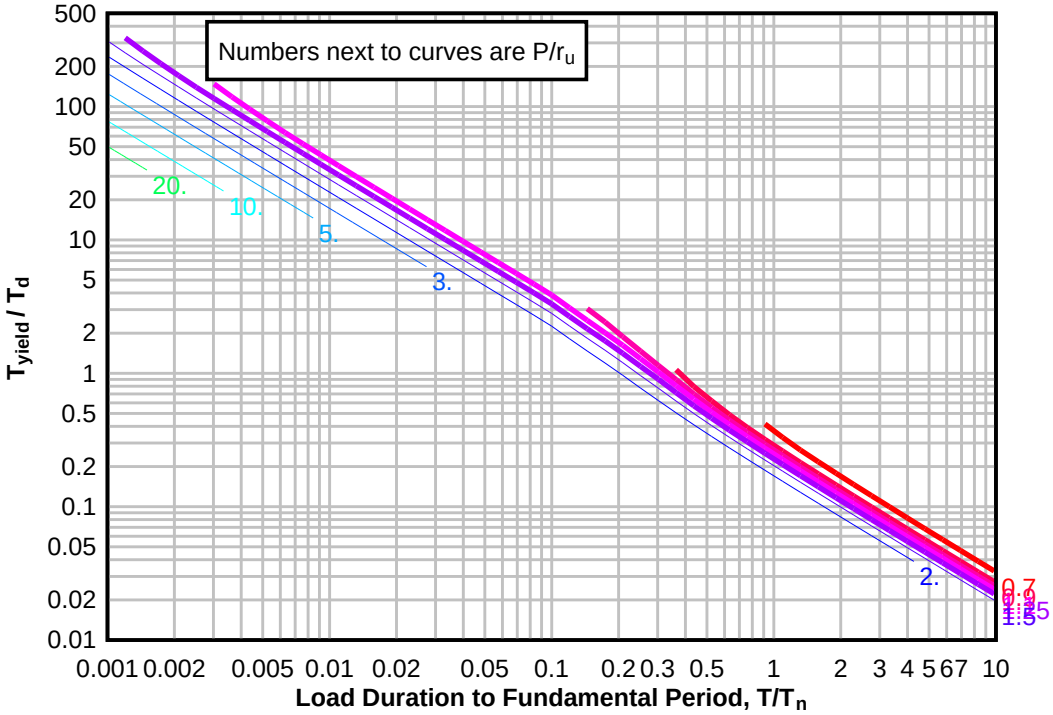


Figure 3-234(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.464, C_2 = 1000)

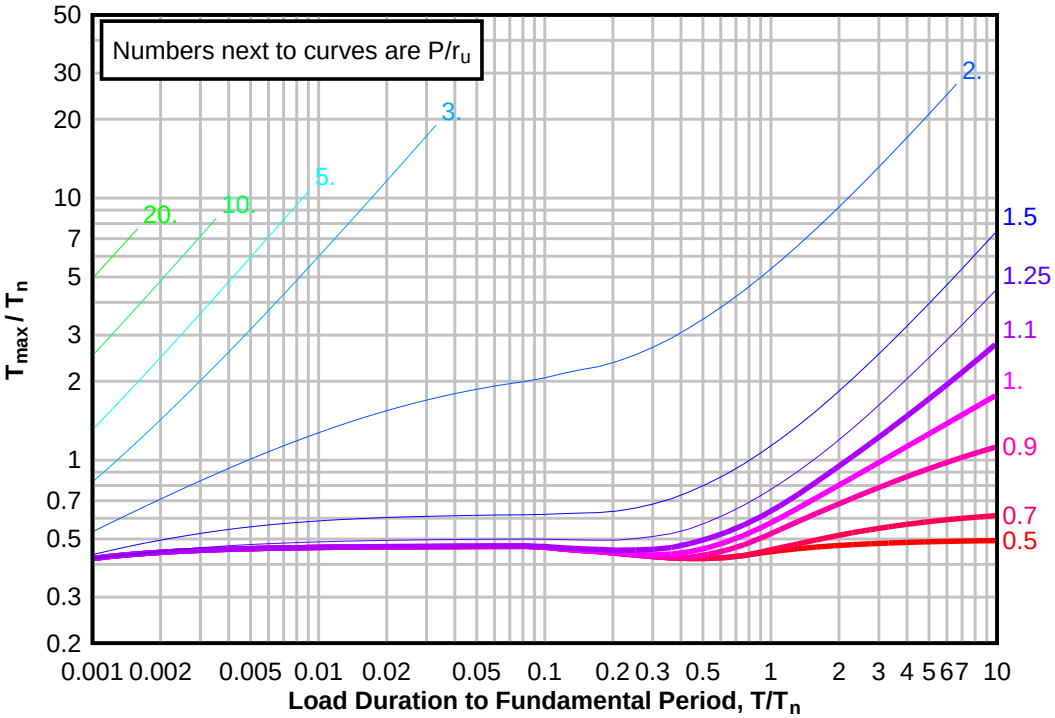


Figure 3-234(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.464, C2 = 1000)

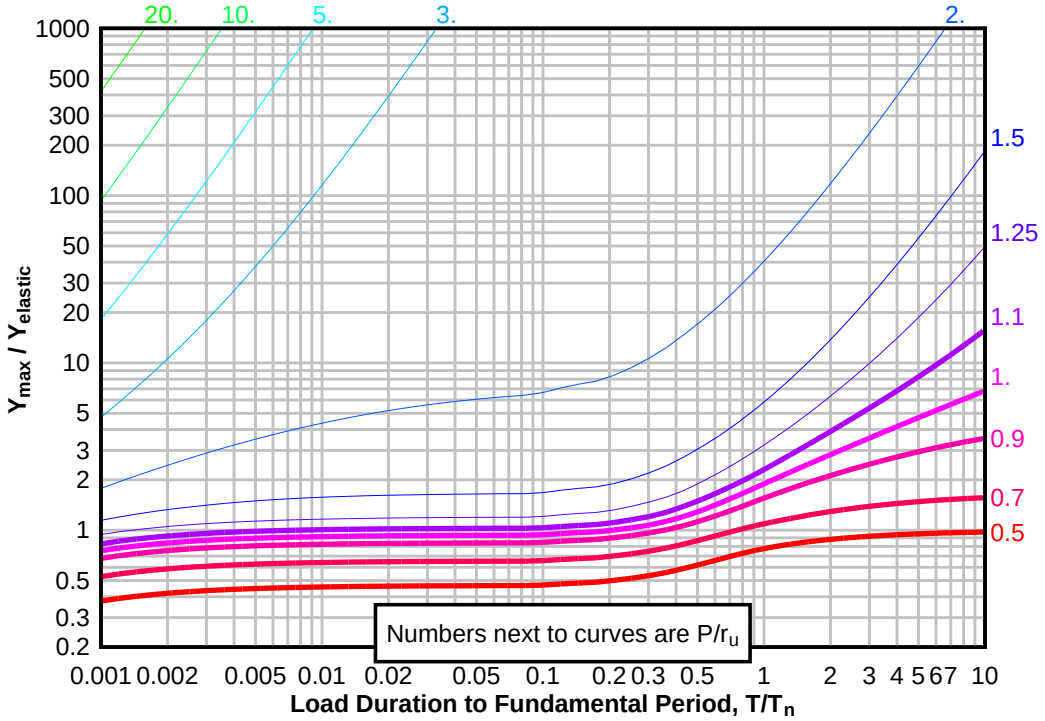


Figure 3-234(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.464, C2 = 1000)

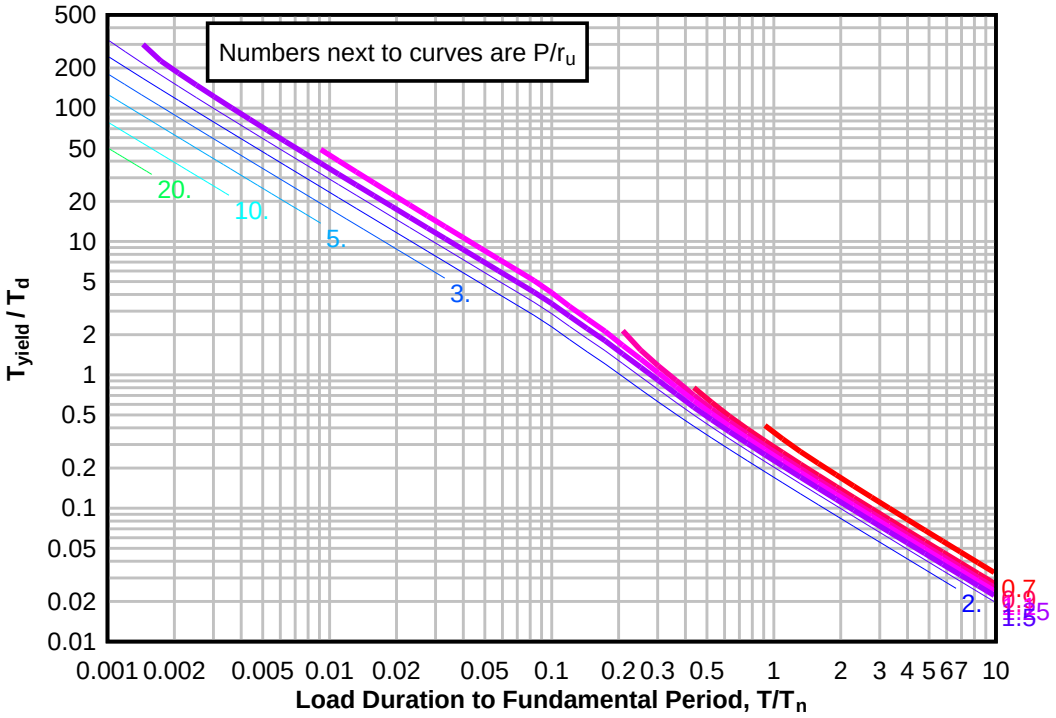


Figure 3-235(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.422, C_2 = 1000)

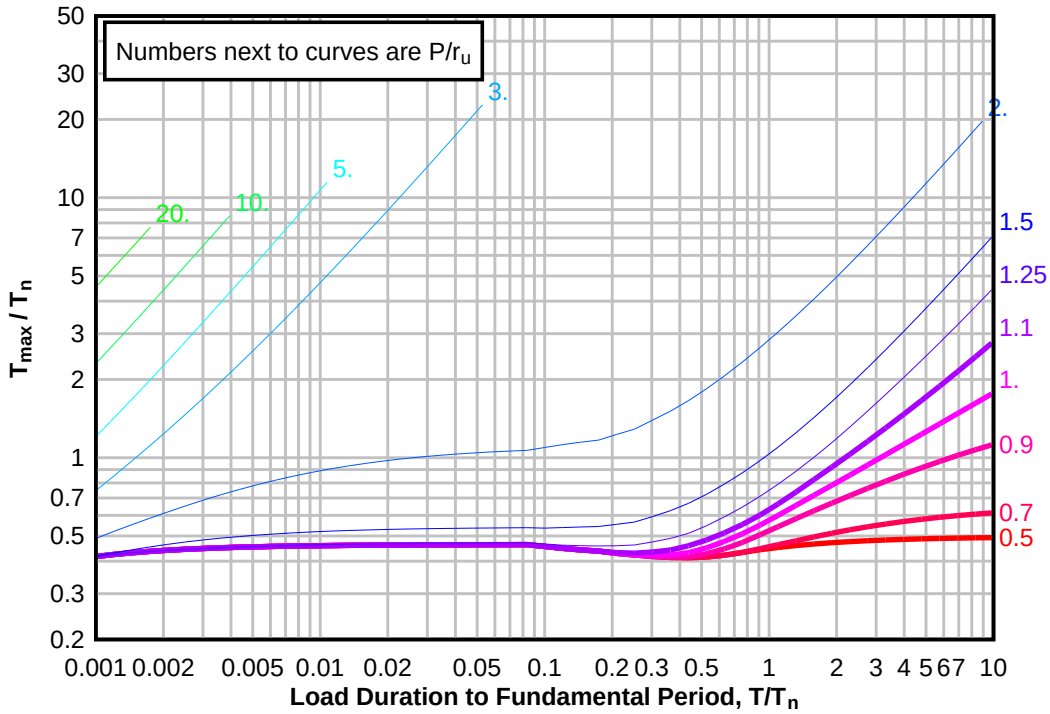


Figure 3-235(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.422, C2 = 1000)

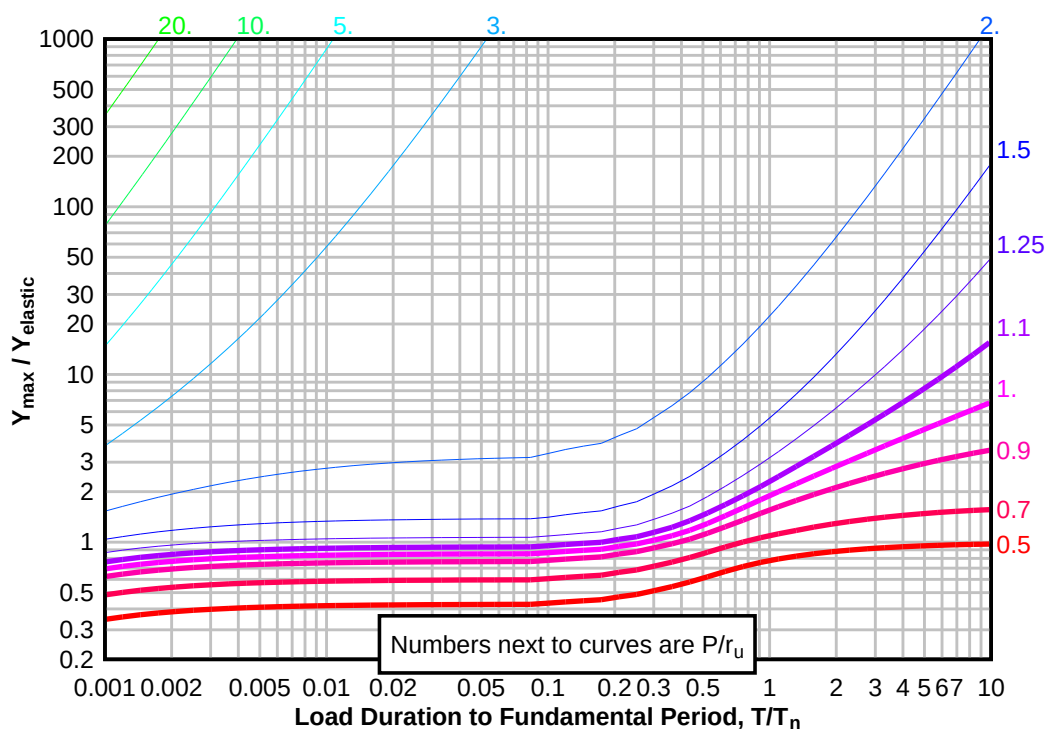


Figure 3-235(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.422, C2 = 1000)

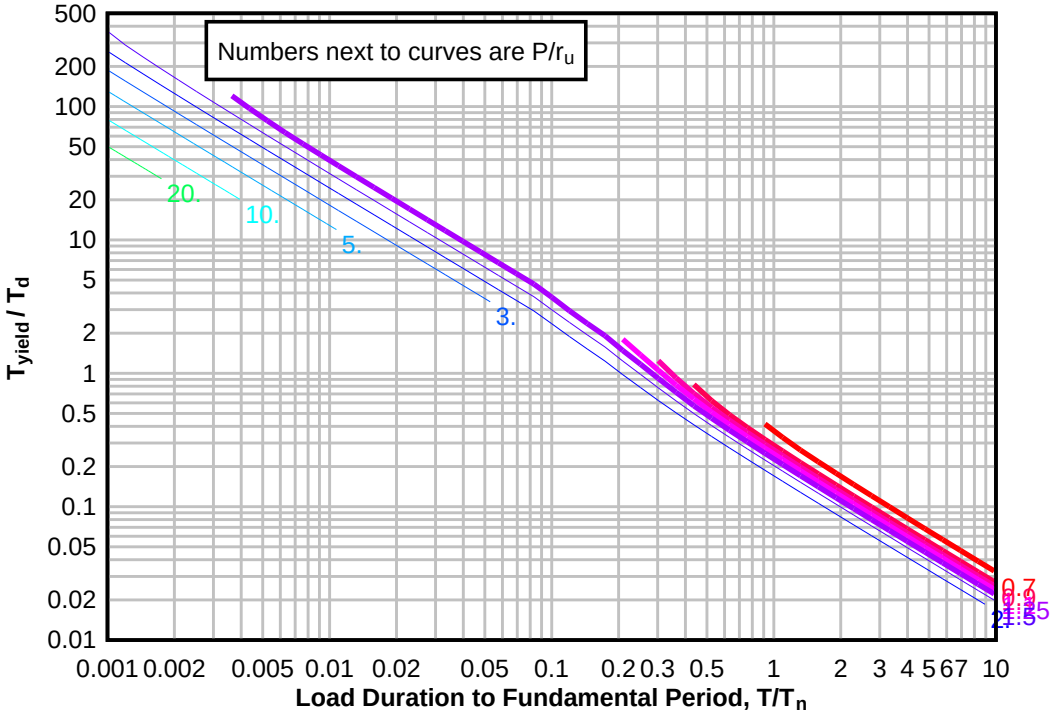


Figure 3-236(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.383, C_2 = 1000)

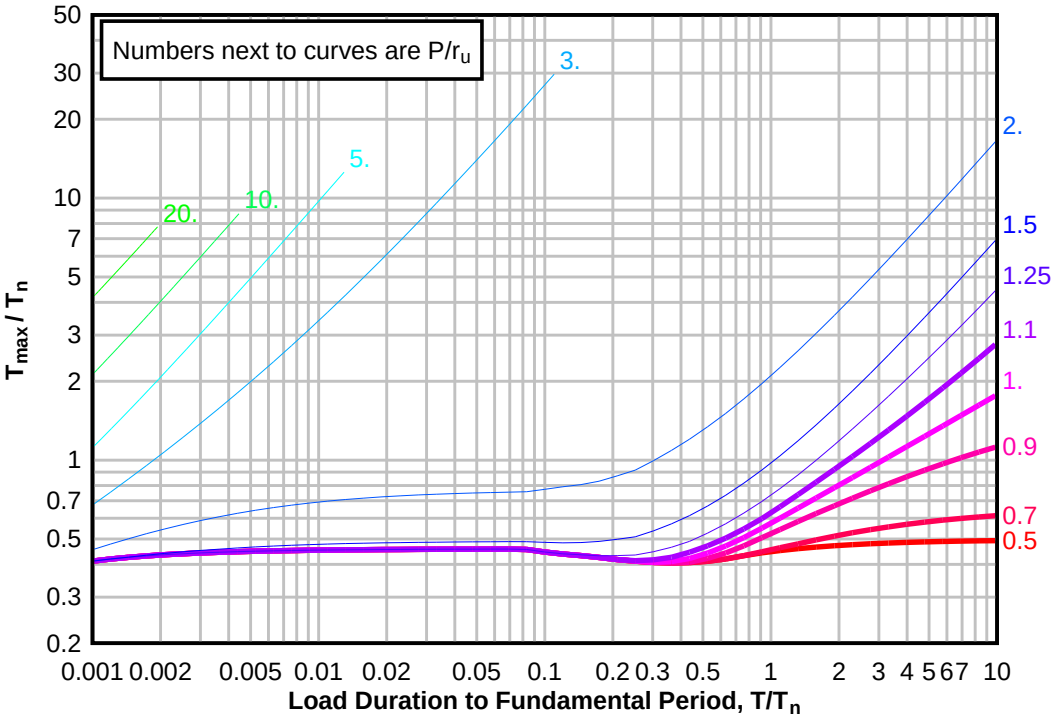


Figure 3-236(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.383, C2 = 1000)

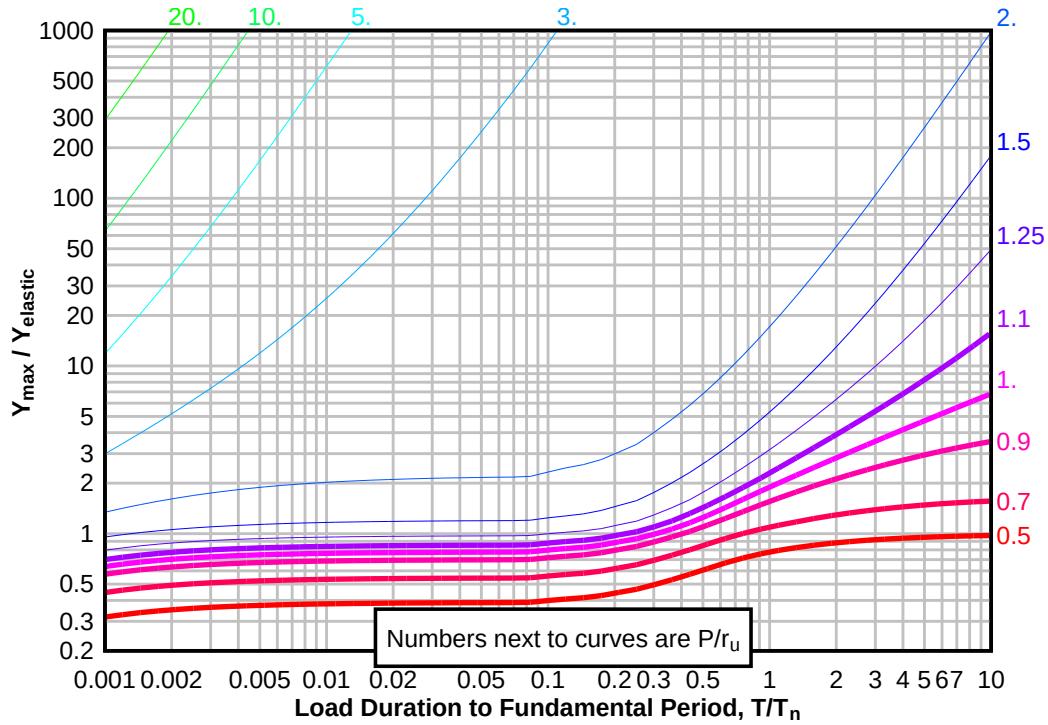


Figure 3-236(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.383, C2 = 1000)

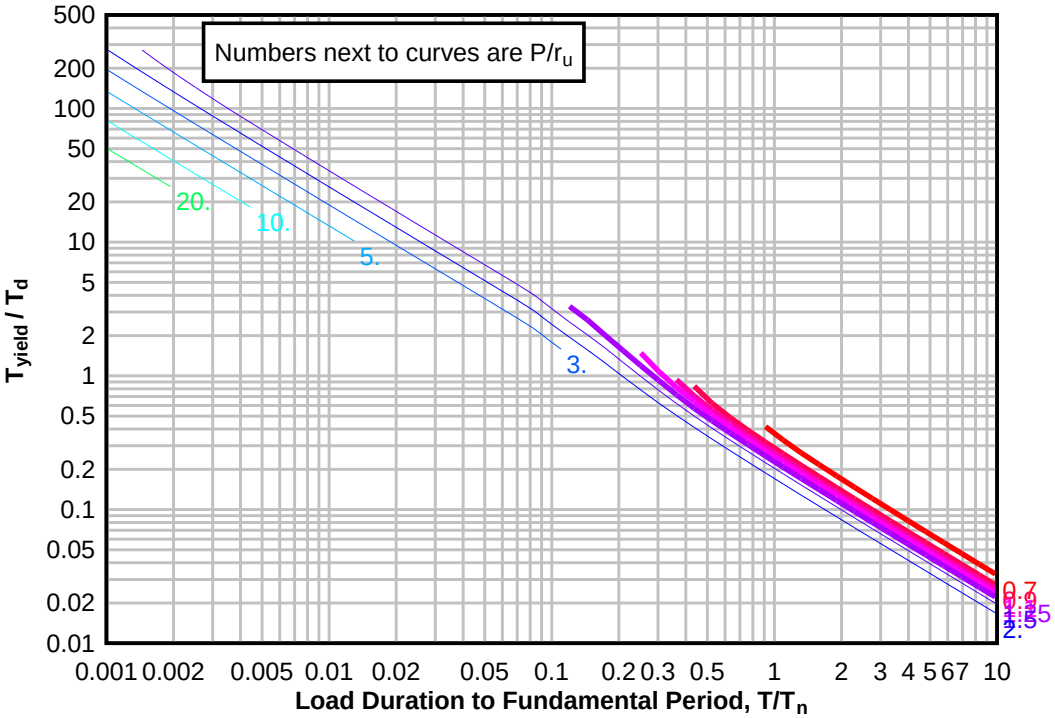


Figure 3-237(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.365, C_2 = 1000)

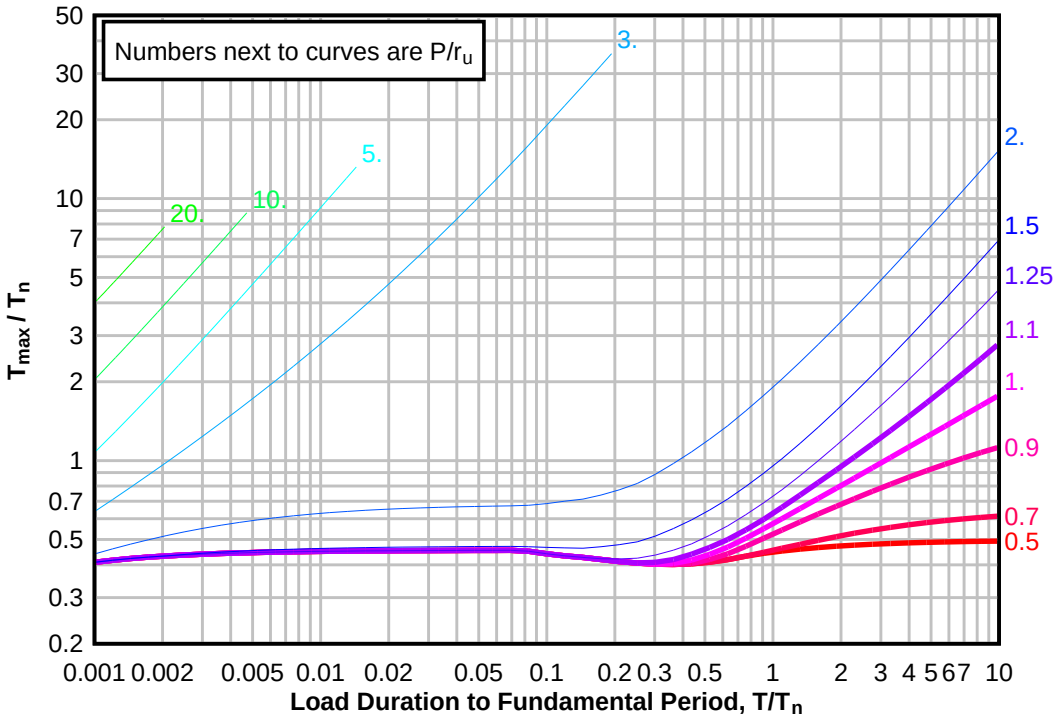


Figure 3-237(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.365, C2 = 1000)

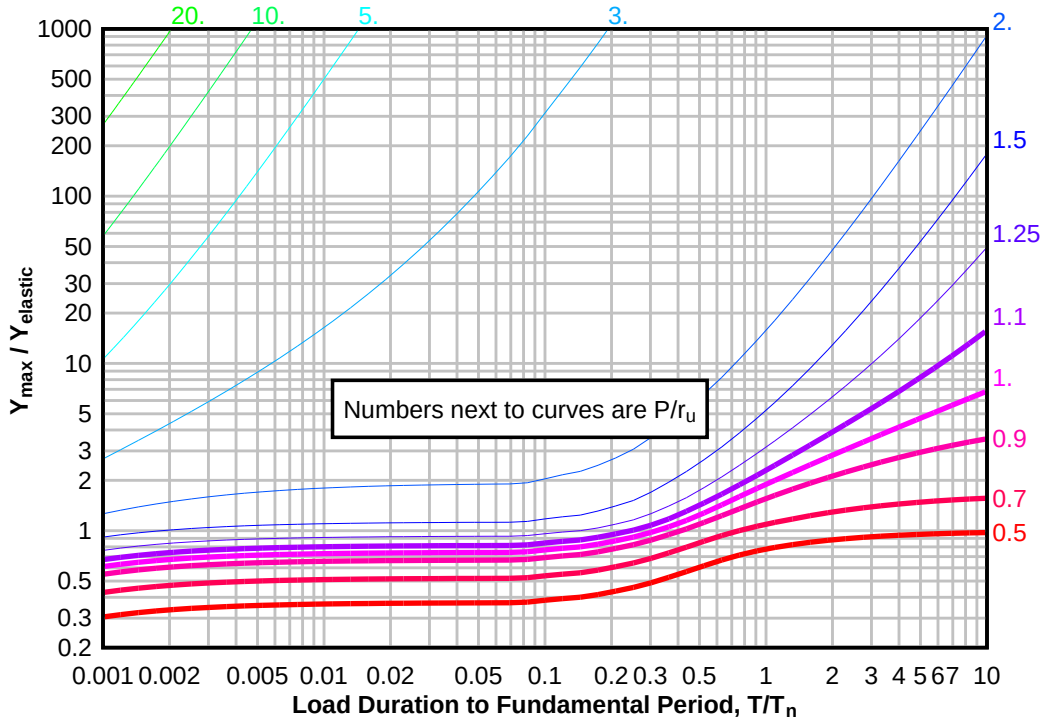


Figure 3-237(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.365, C2 = 1000)

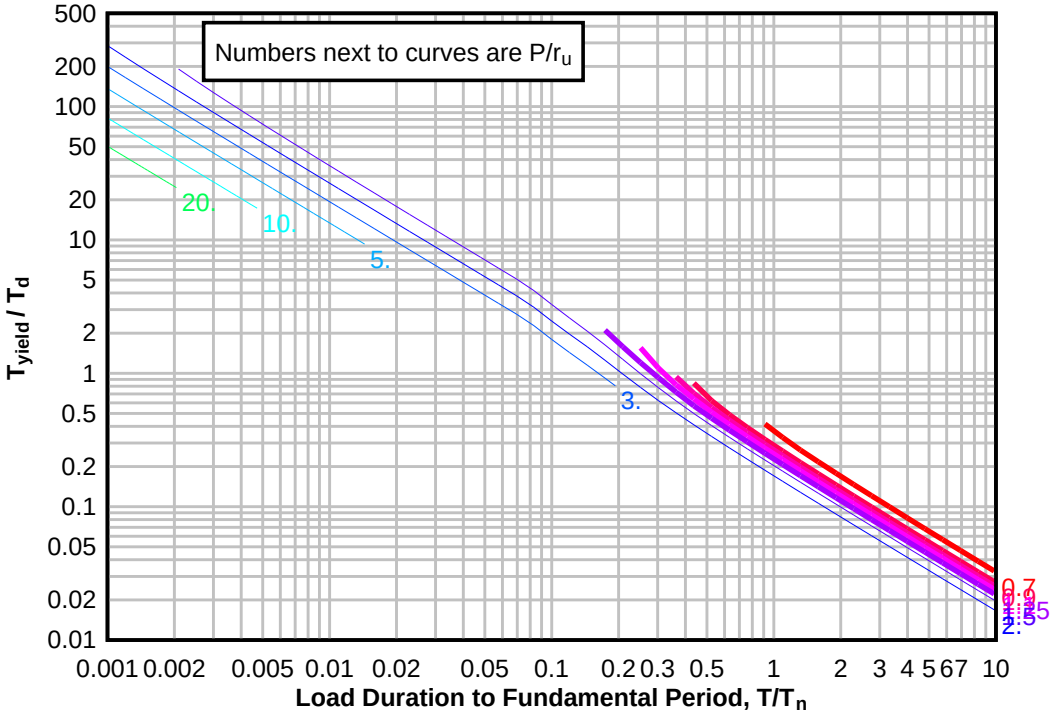


Figure 3-238(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.348, C_2 = 1000)

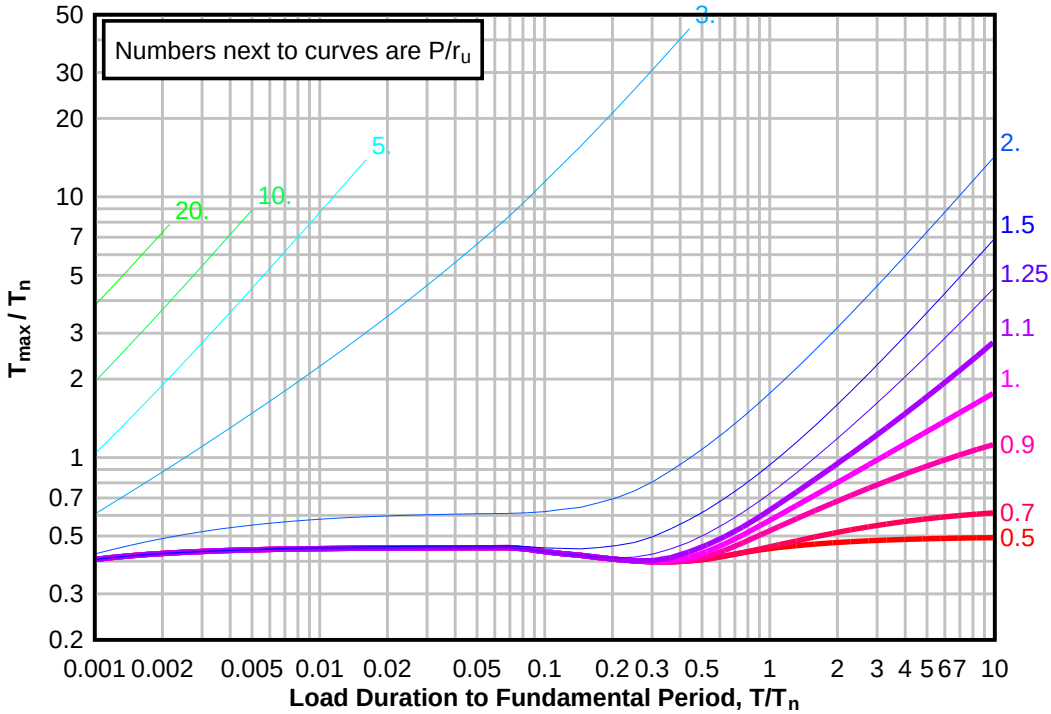


Figure 3-238(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.348, C2 = 1000)

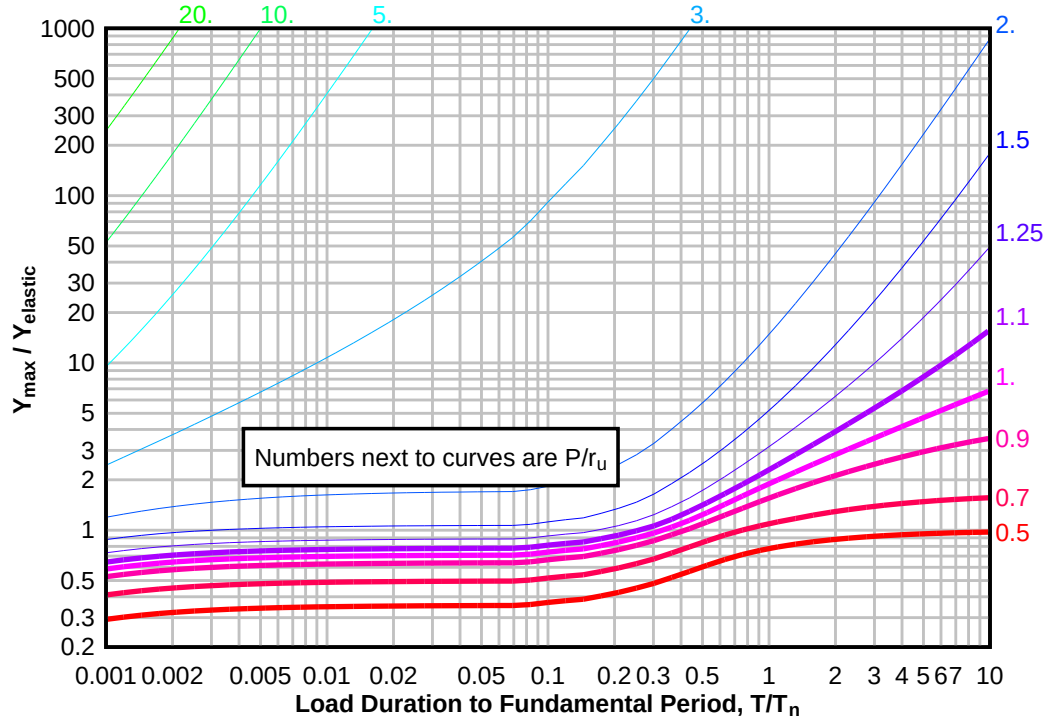


Figure 3-238(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.348, C2 = 1000)

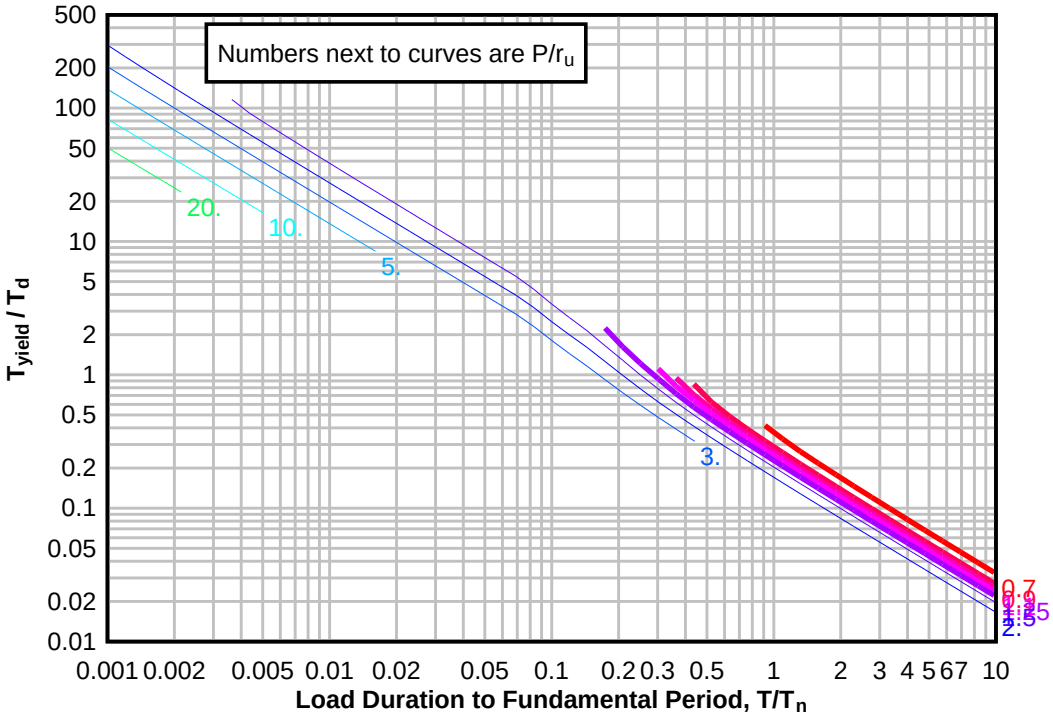


Figure 3-239(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.316, C_2 = 1000)

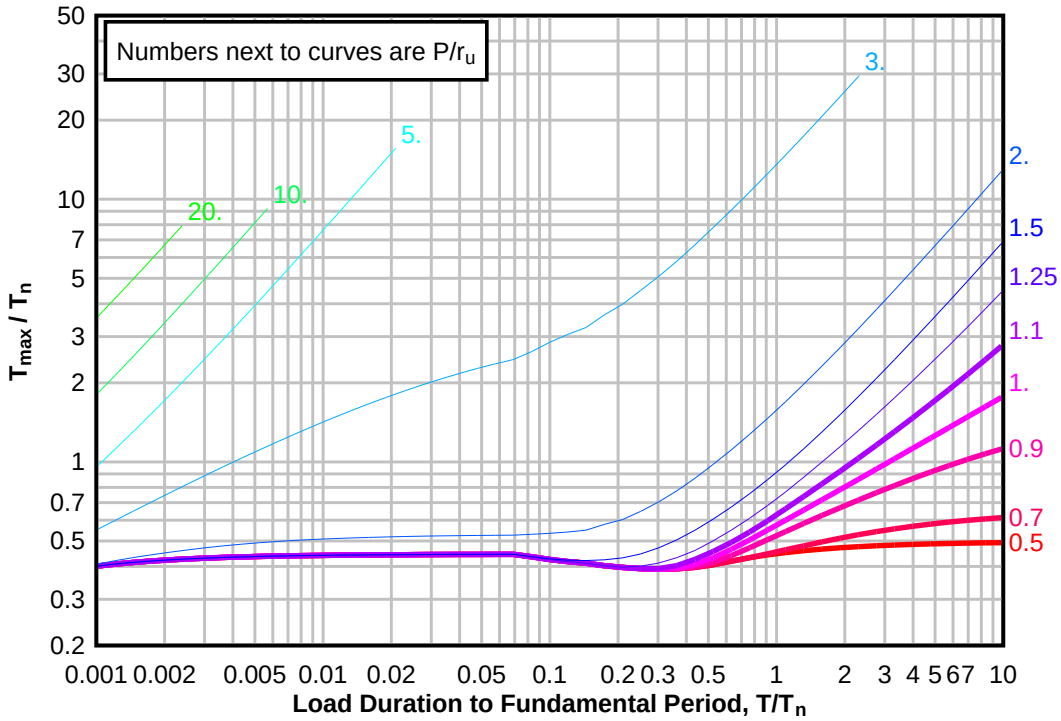


Figure 3-239(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.316, C2 = 1000)

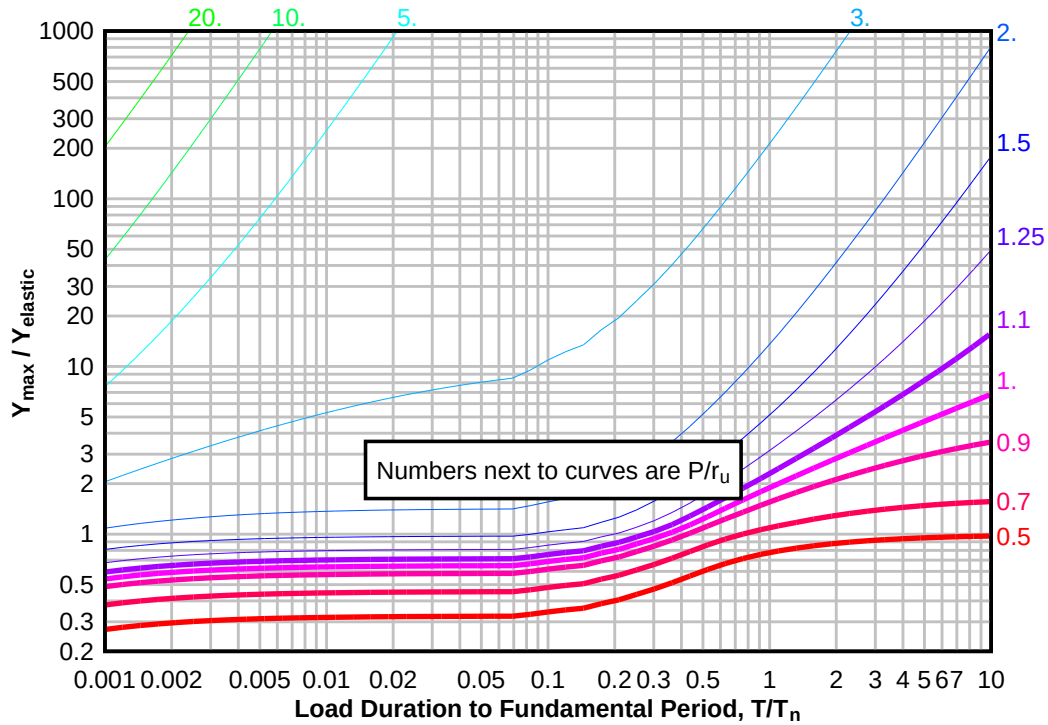


Figure 3-239(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.316, C2 = 1000)

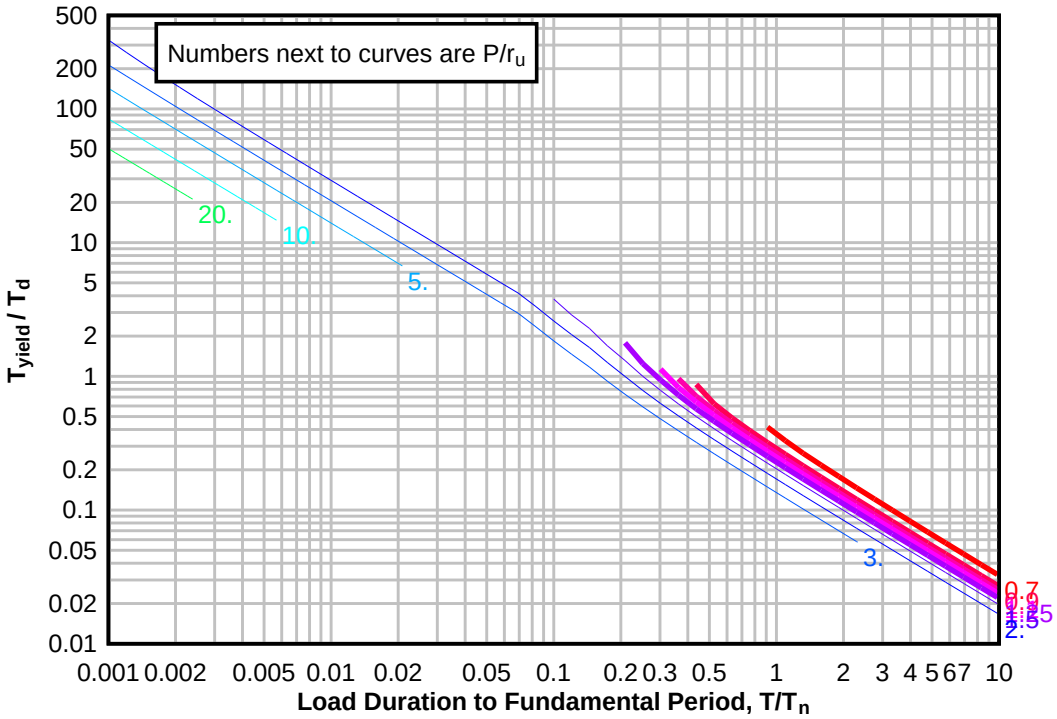


Figure 3-240(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.287, C_2 = 1000)

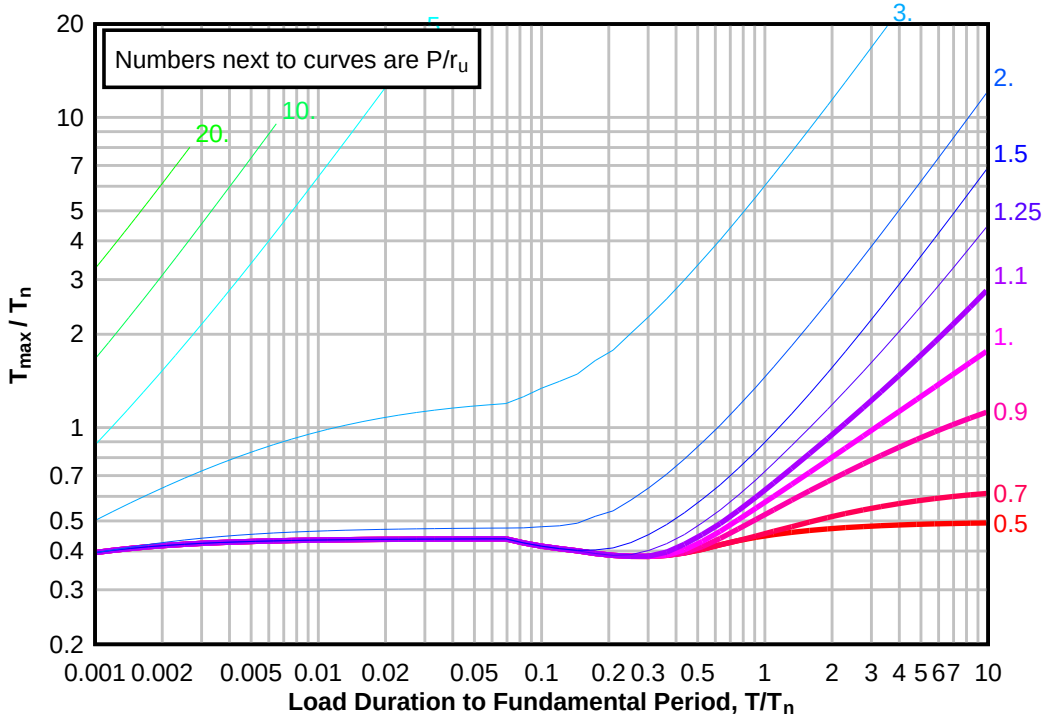


Figure 3-240(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.287, C2 = 1000)

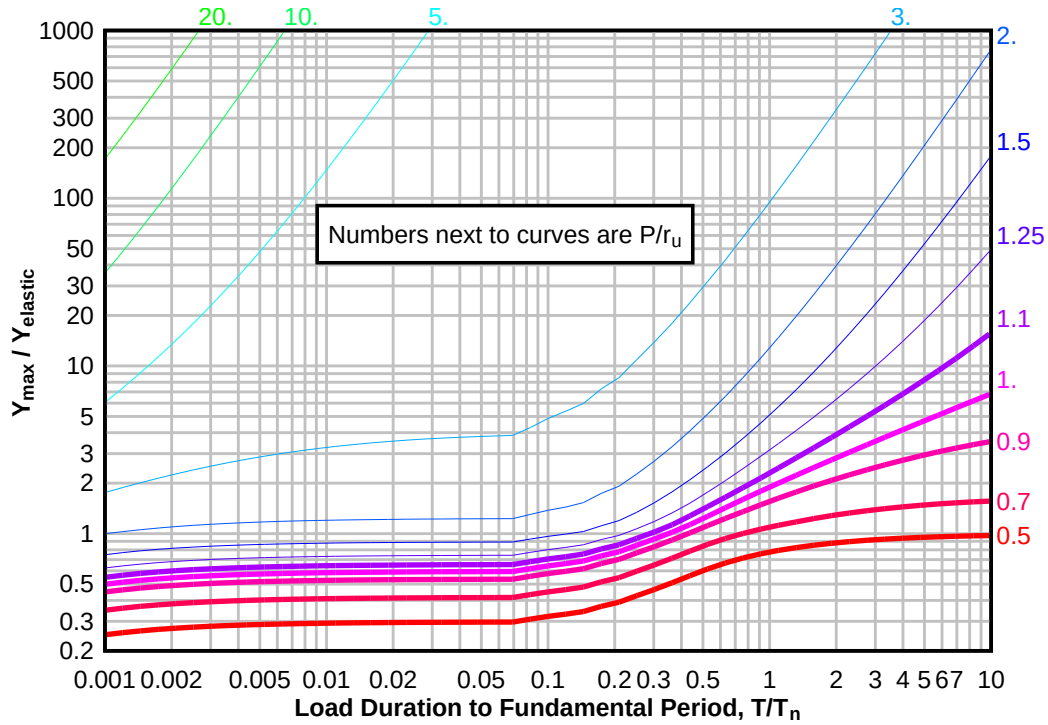


Figure 3-240(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.287, C2 = 1000)

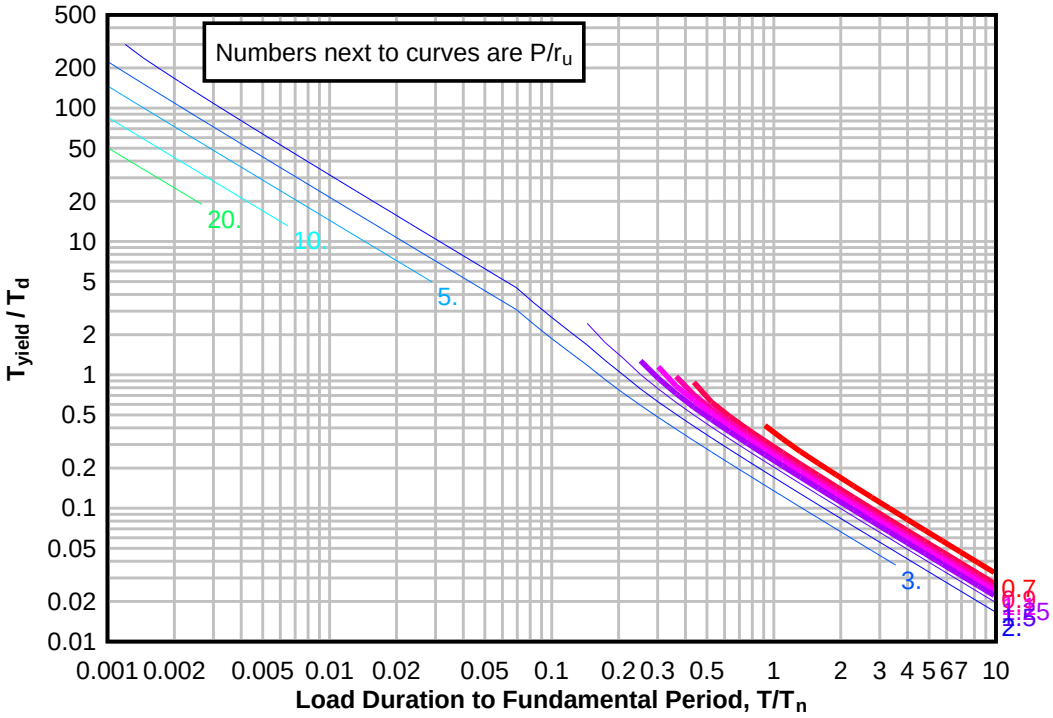


Figure 3-241(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.274, C_2 = 1000)

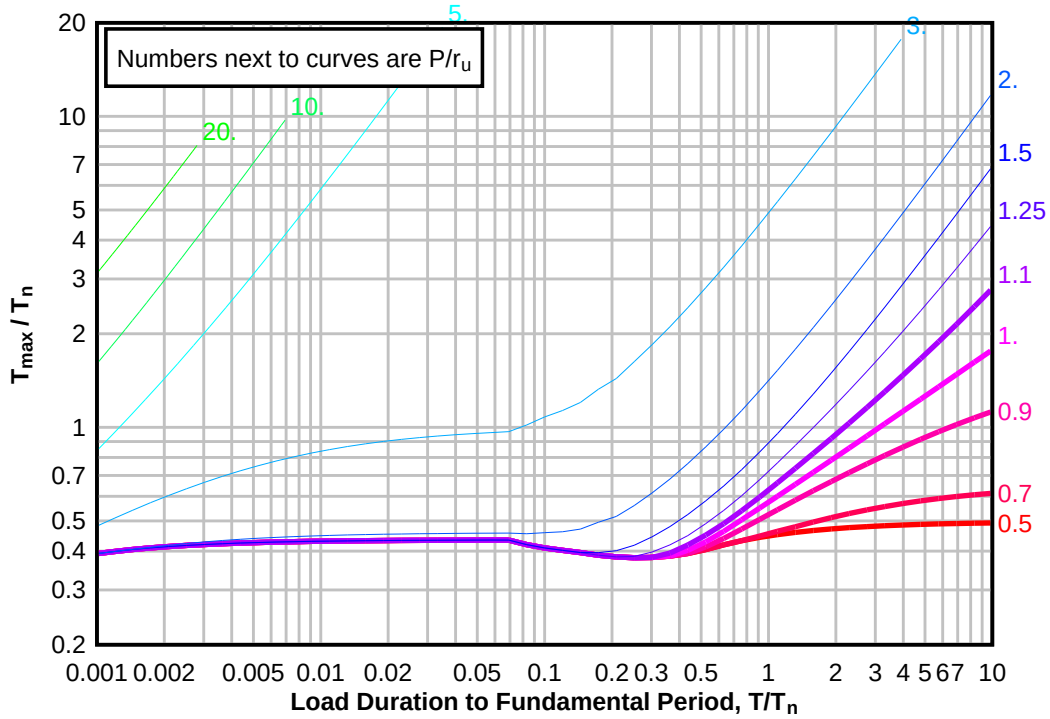


Figure 3-241(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.274, C2 = 1000)

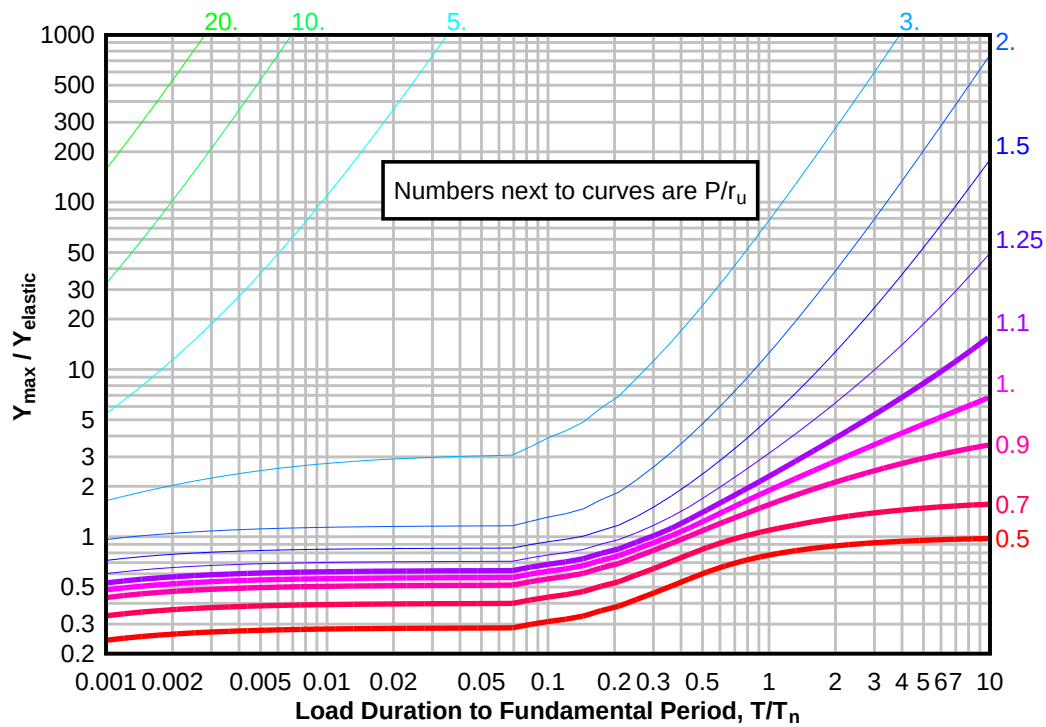


Figure 3-241(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.274, C2 = 1000)

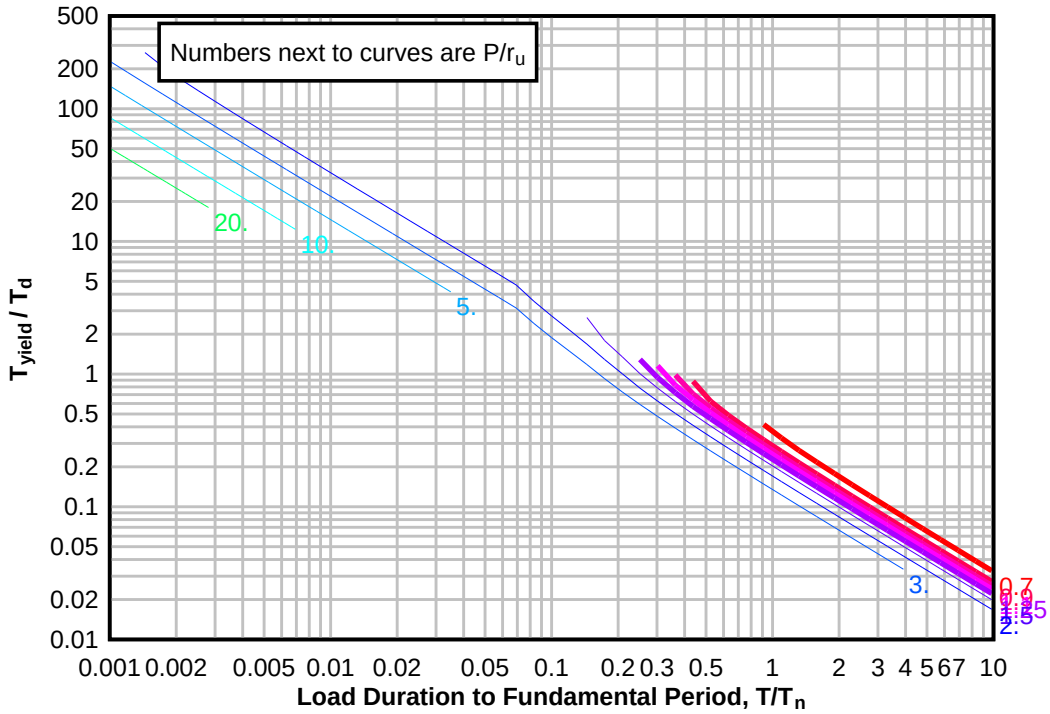


Figure 3-242(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.261, C_2 = 1000)

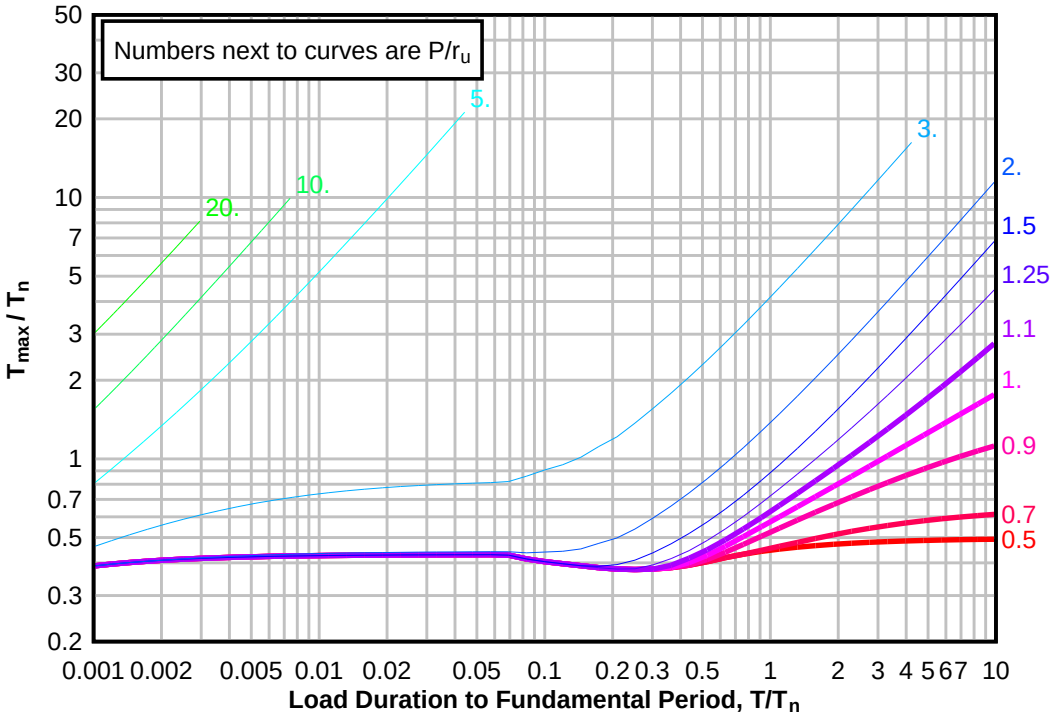


Figure 3-242(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.261, C2 = 1000)

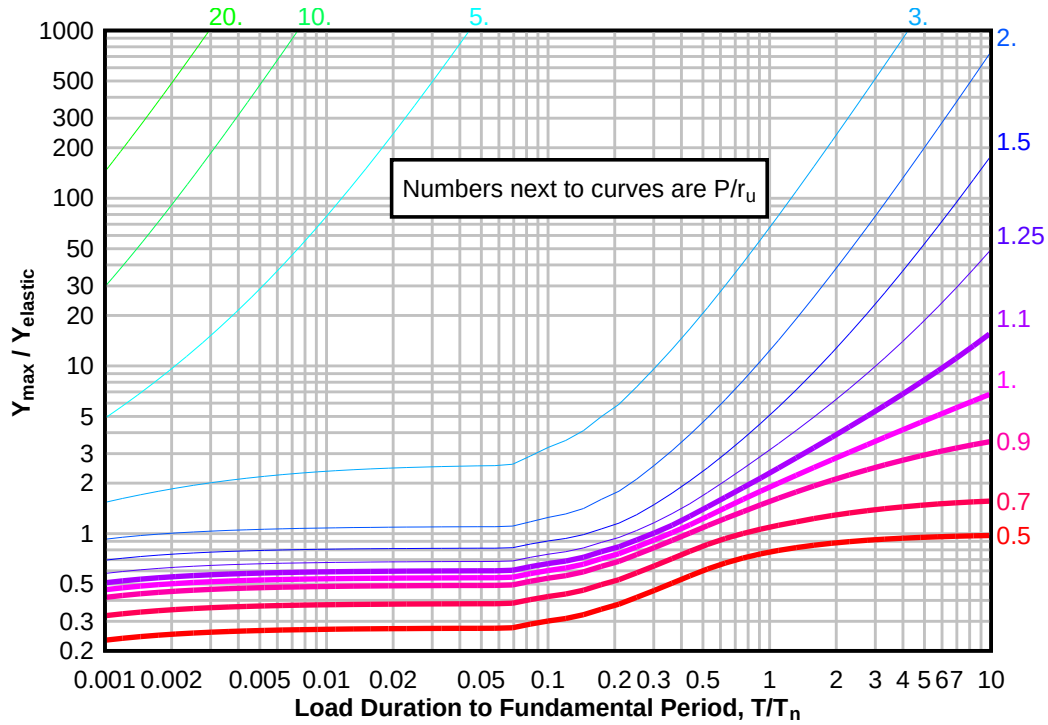


Figure 3-242(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.261, C2 = 1000)

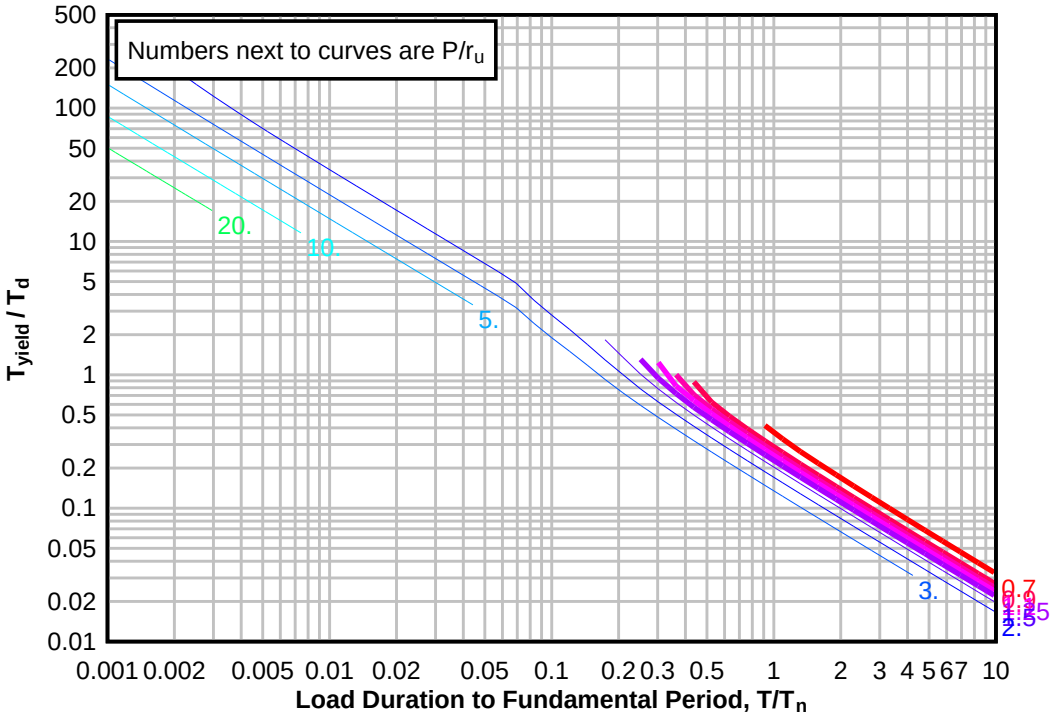


Figure 3-243(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.237, C_2 = 1000)

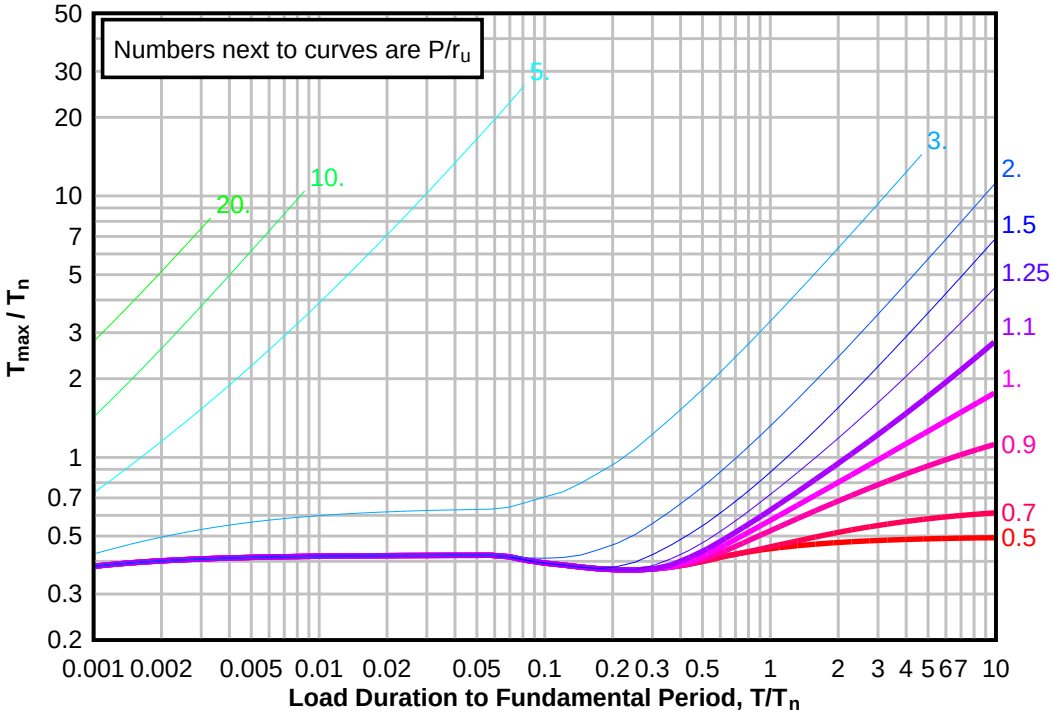


Figure 3-243(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.237, C2 = 1000)

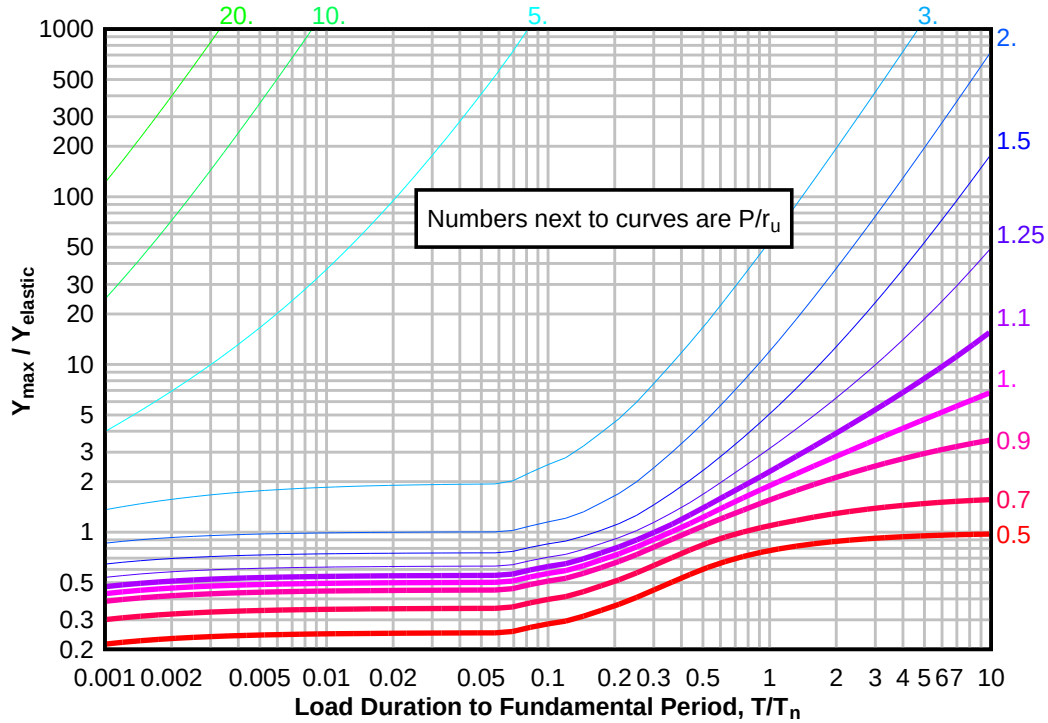


Figure 3-243(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.237, C2 = 1000)

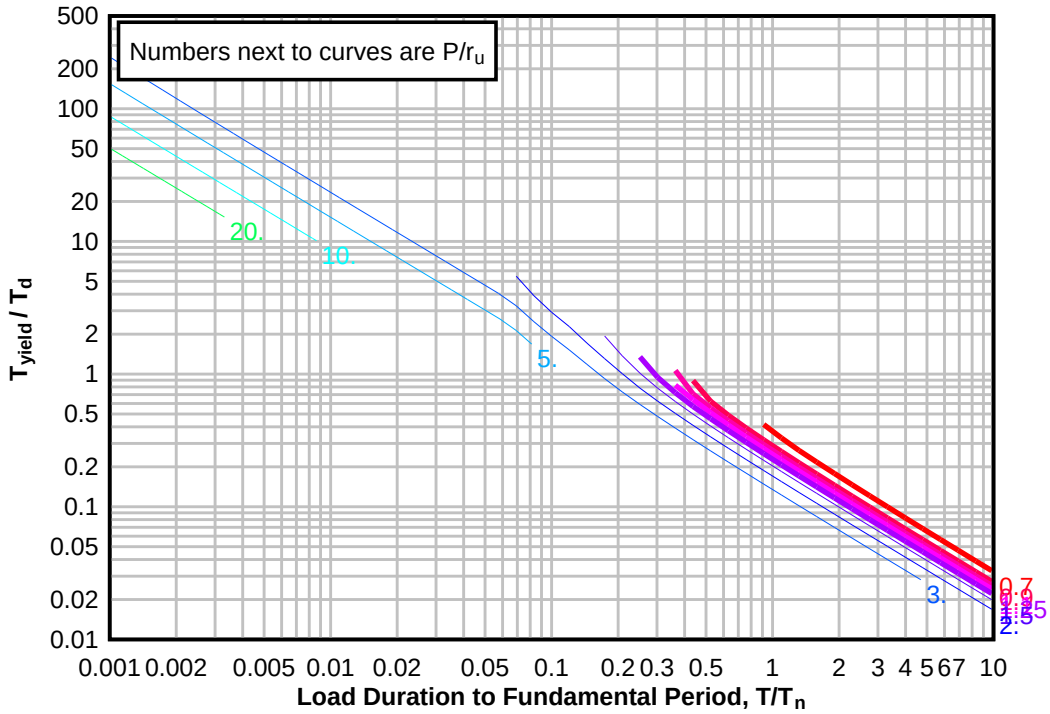


Figure 3-244(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.215, C_2 = 1000)

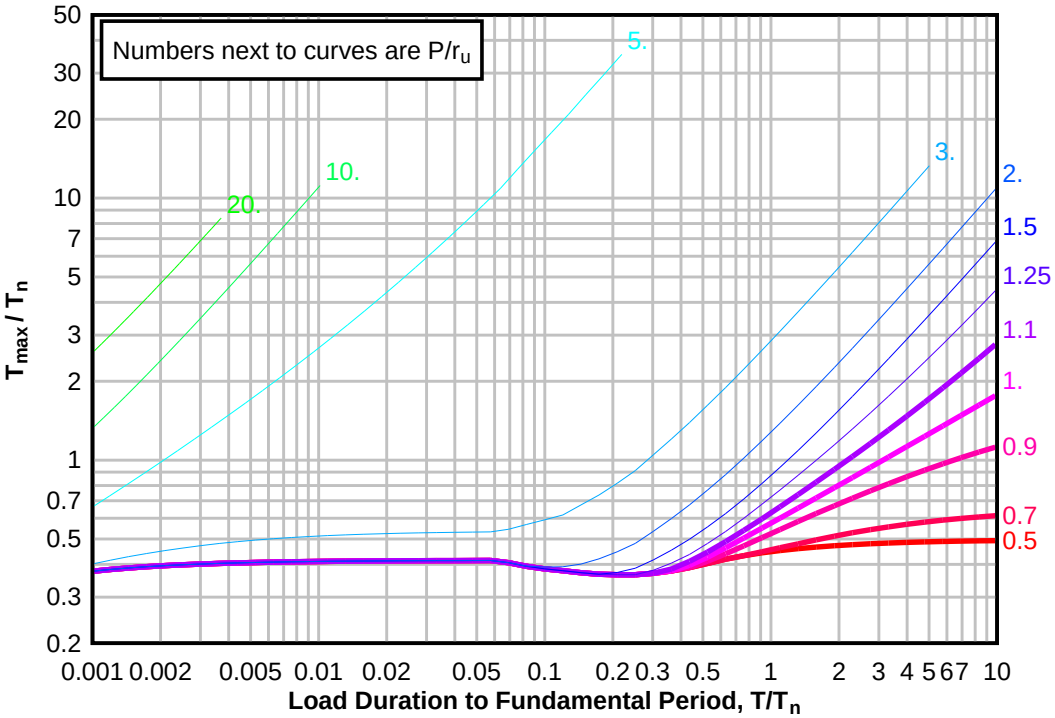


Figure 3-244(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.215, C2 = 1000)

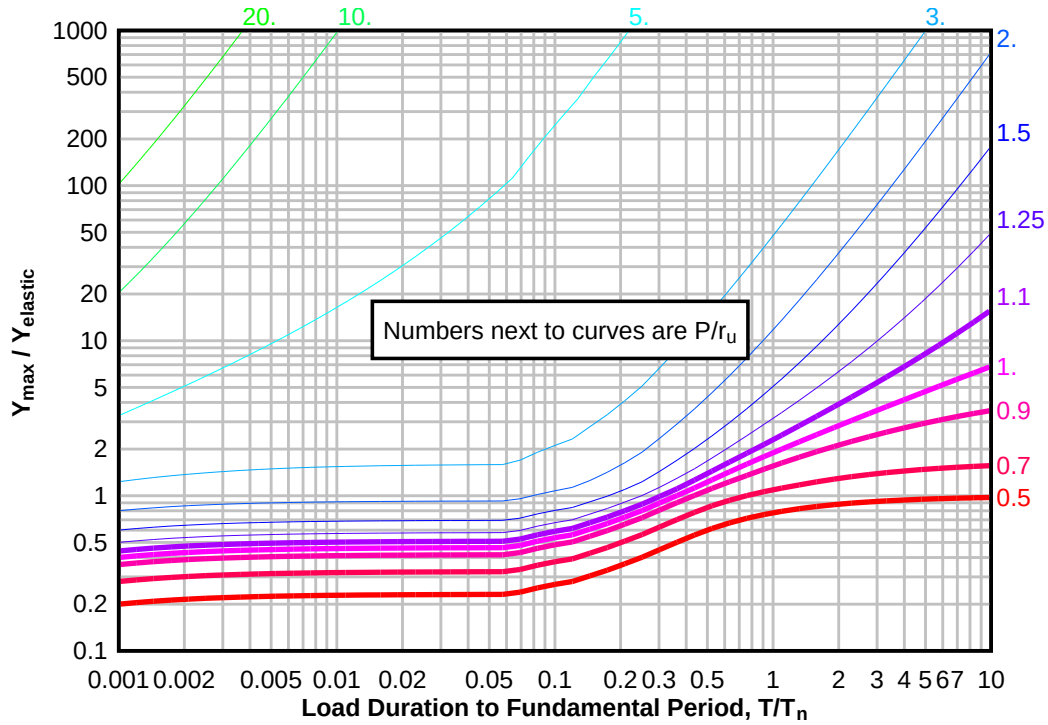


Figure 3-244(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.215, C2 = 1000)

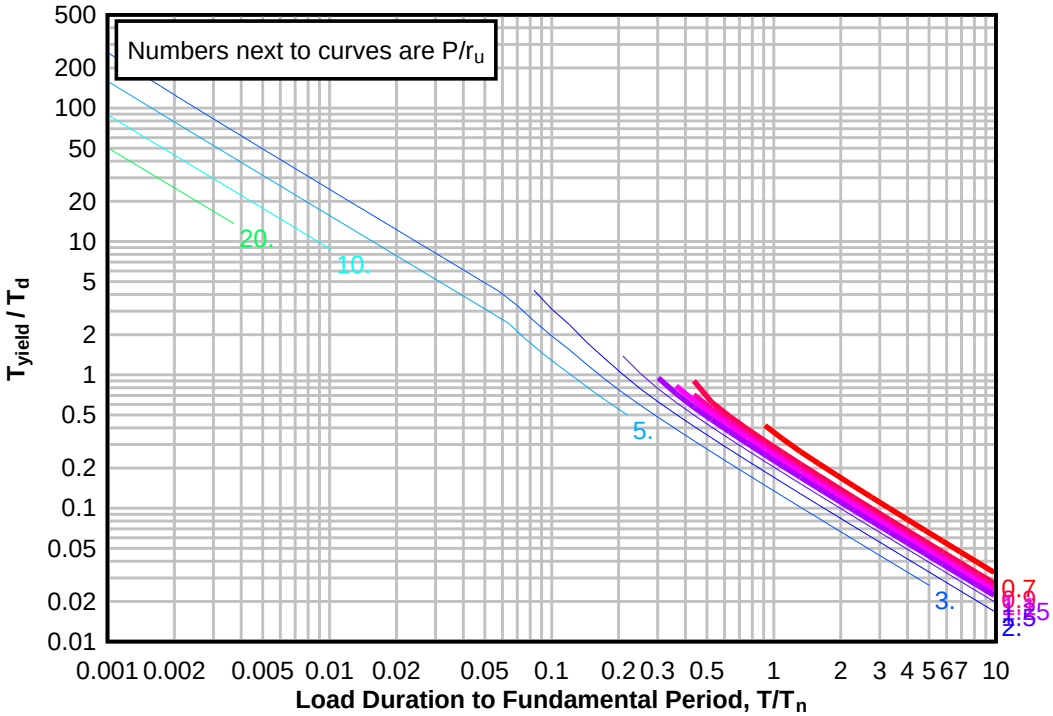


Figure 3-245(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.198, C_2 = 1000)

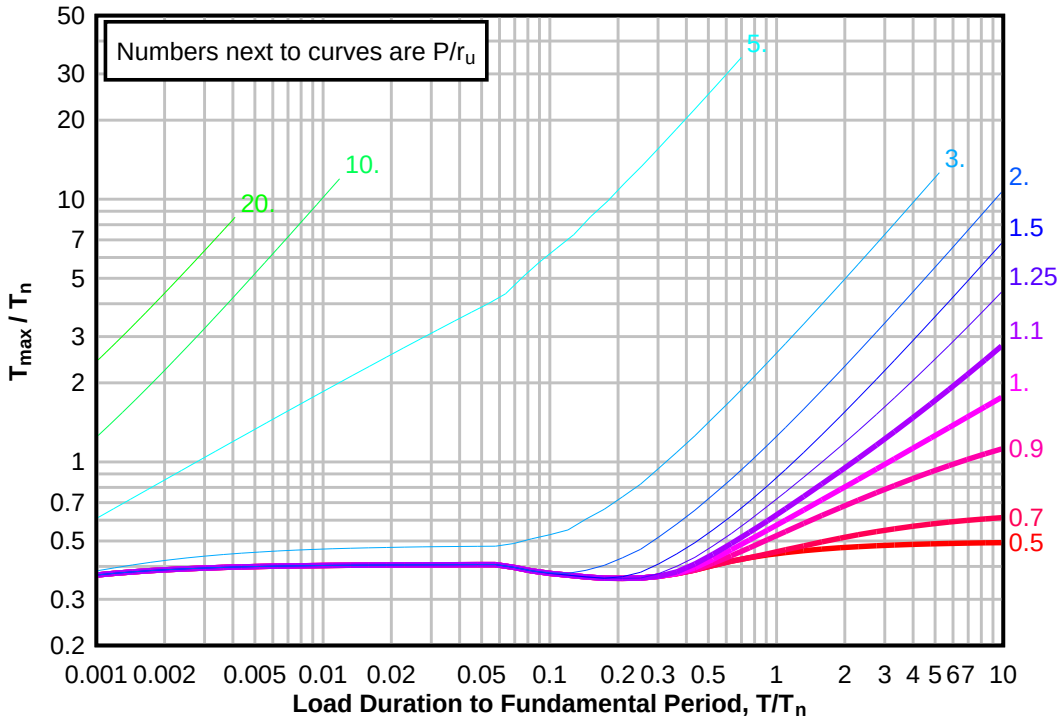


Figure 3-245(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.198, C2 = 1000)

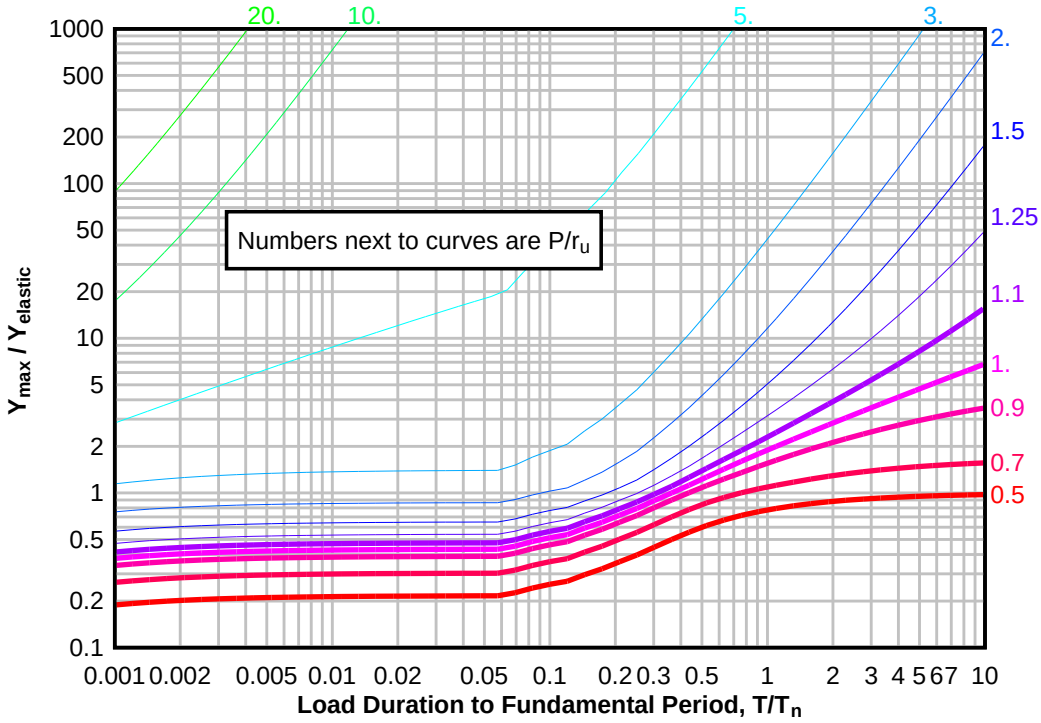


Figure 3-245(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.198, C2 = 1000)

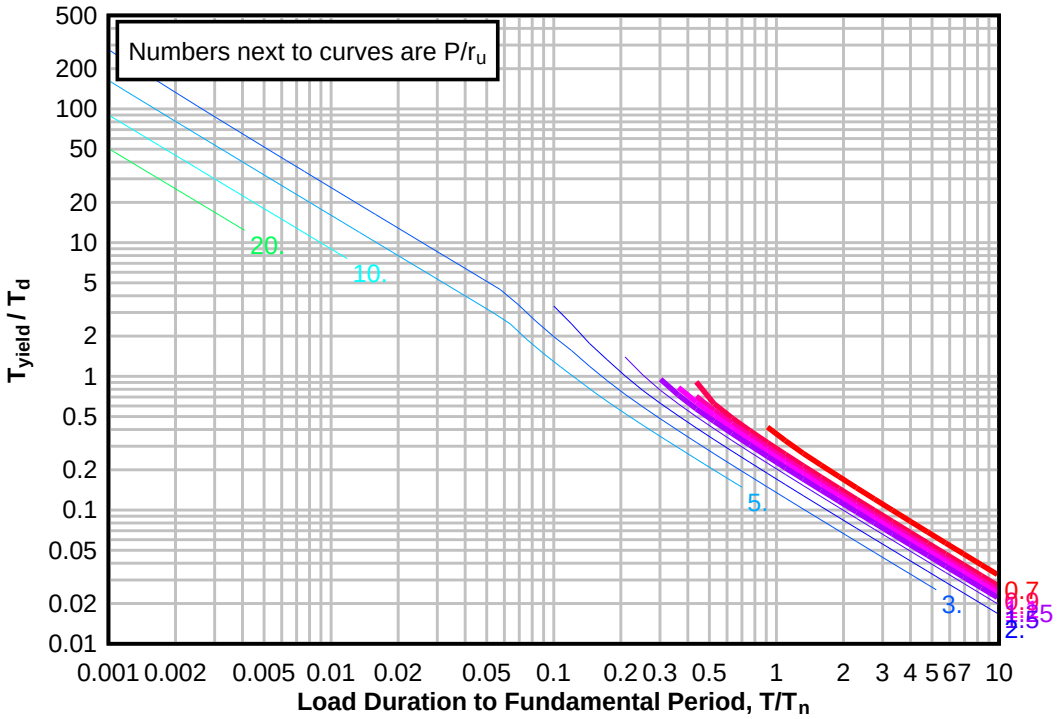


Figure 3-246(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.178, C_2 = 1000)

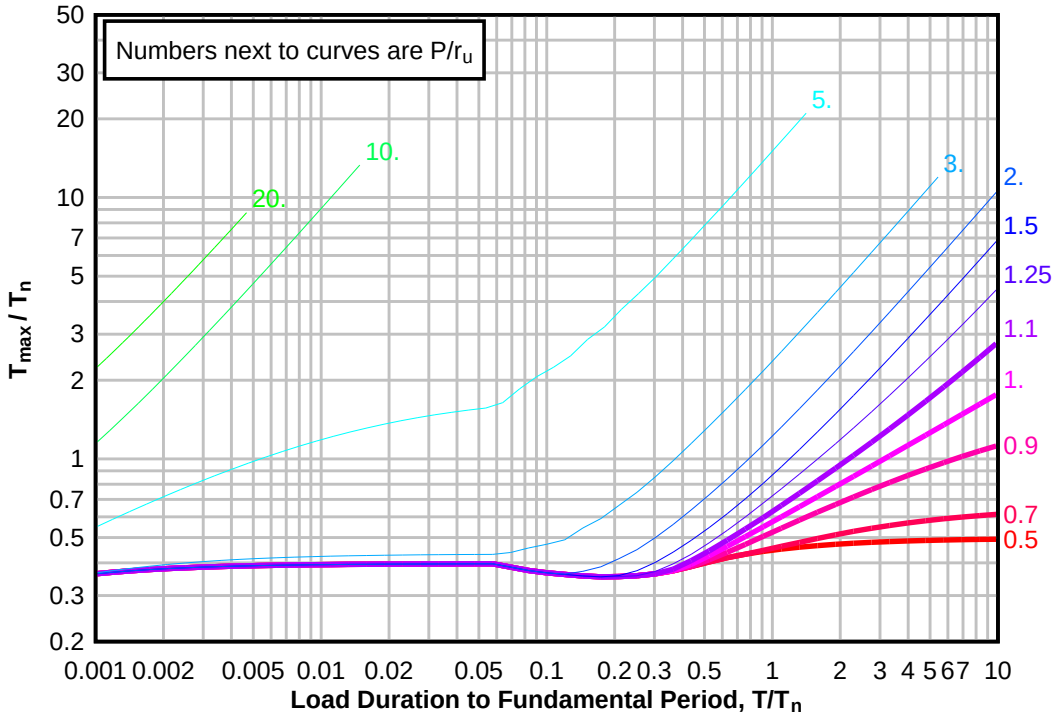


Figure 3-246(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.178, C2 = 1000)

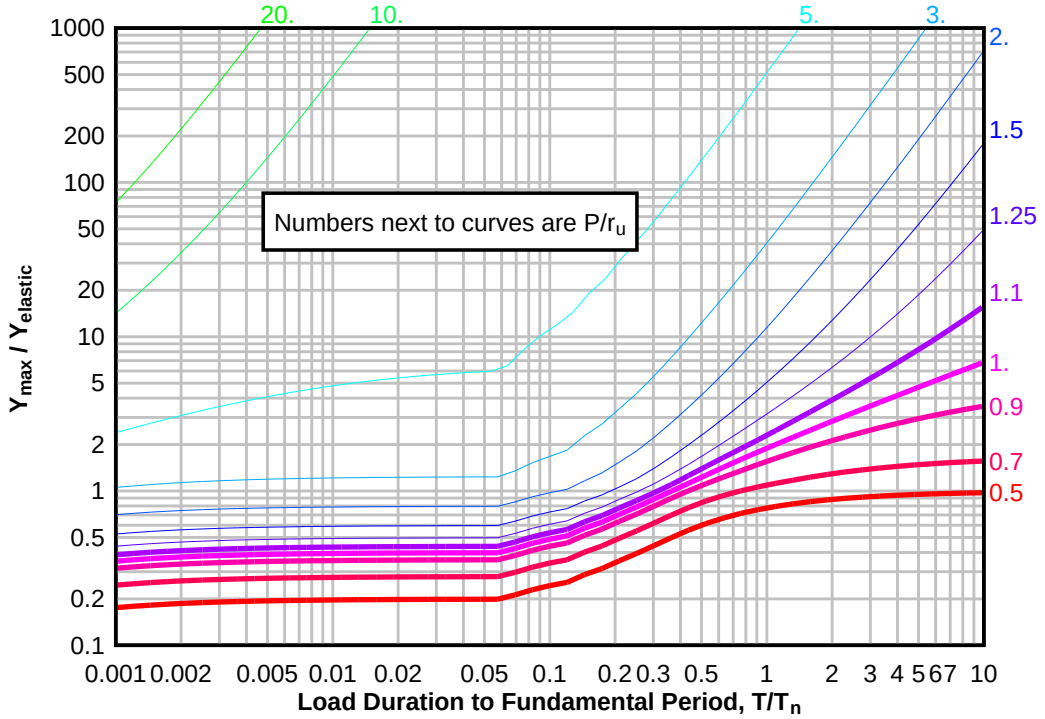


Figure 3-246(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.178, C2 = 1000)

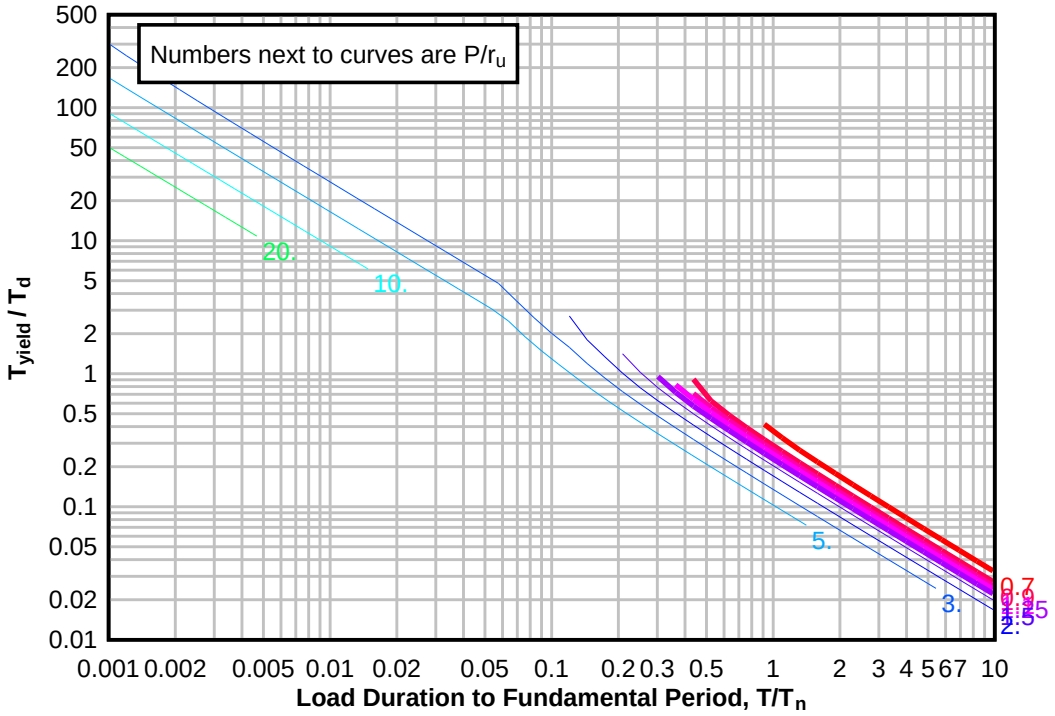


Figure 3-247(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.162, C_2 = 1000)

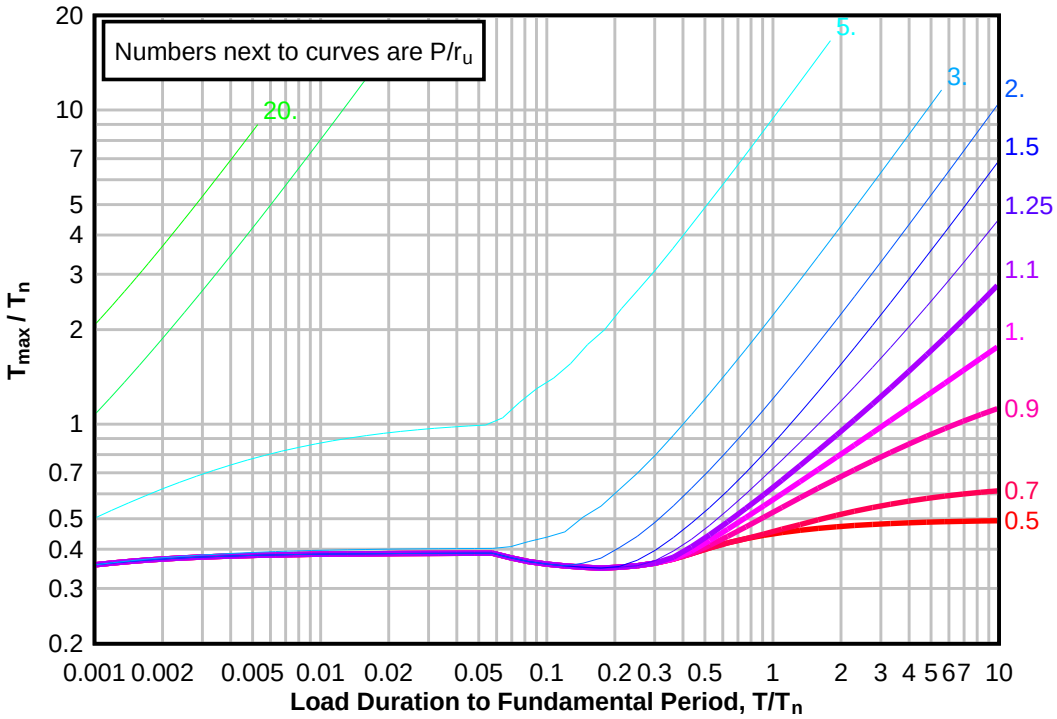


Figure 3-247(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.162, C2 = 1000)

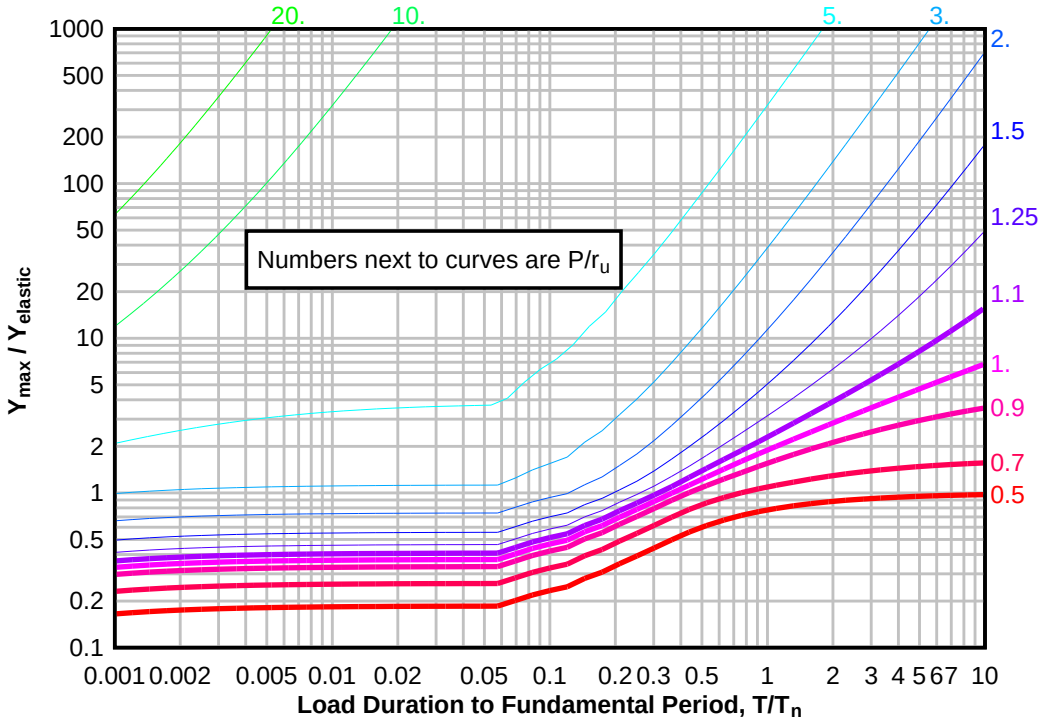


Figure 3-247(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.162, C2 = 1000)

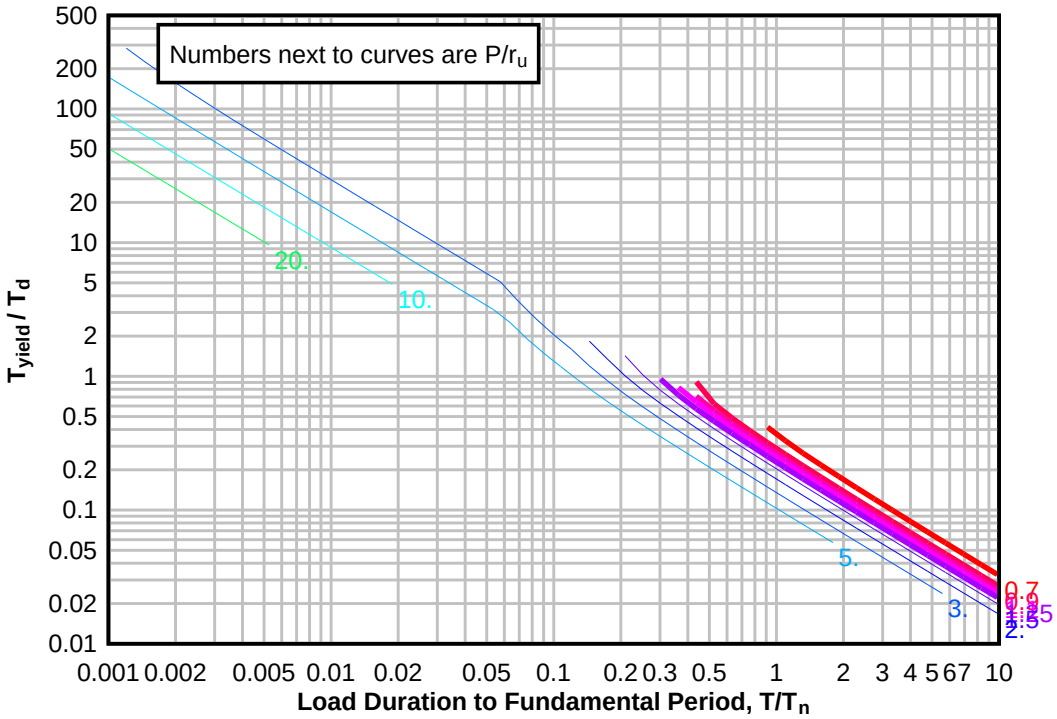


Figure 3-248(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.147, C_2 = 1000)

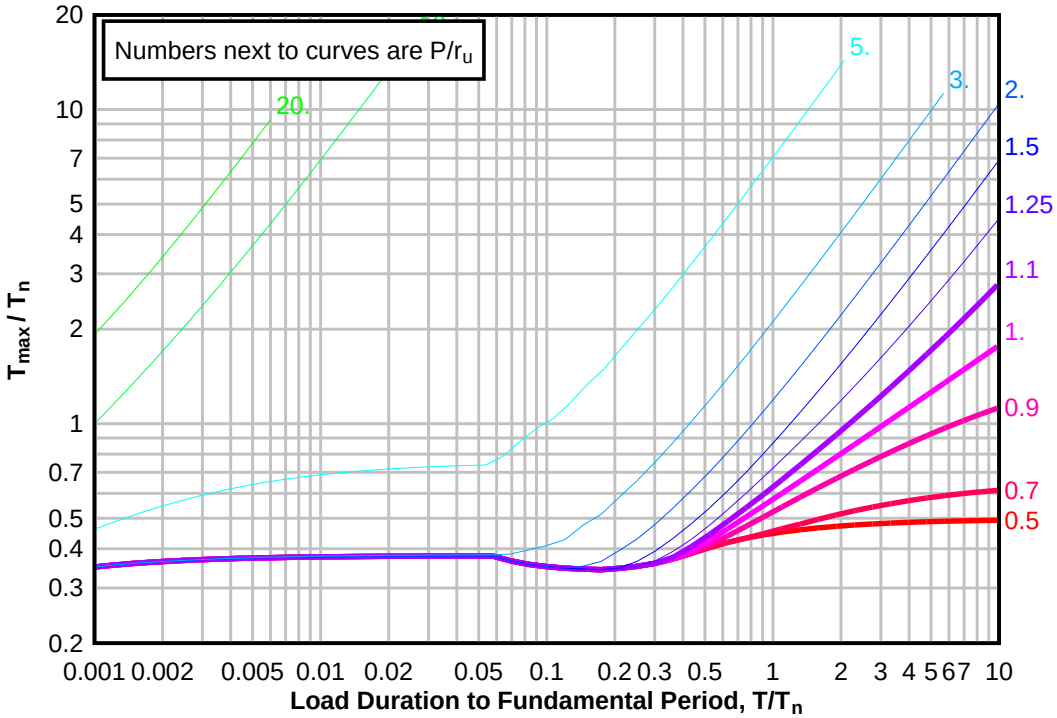


Figure 3-248(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.147, C2 = 1000)

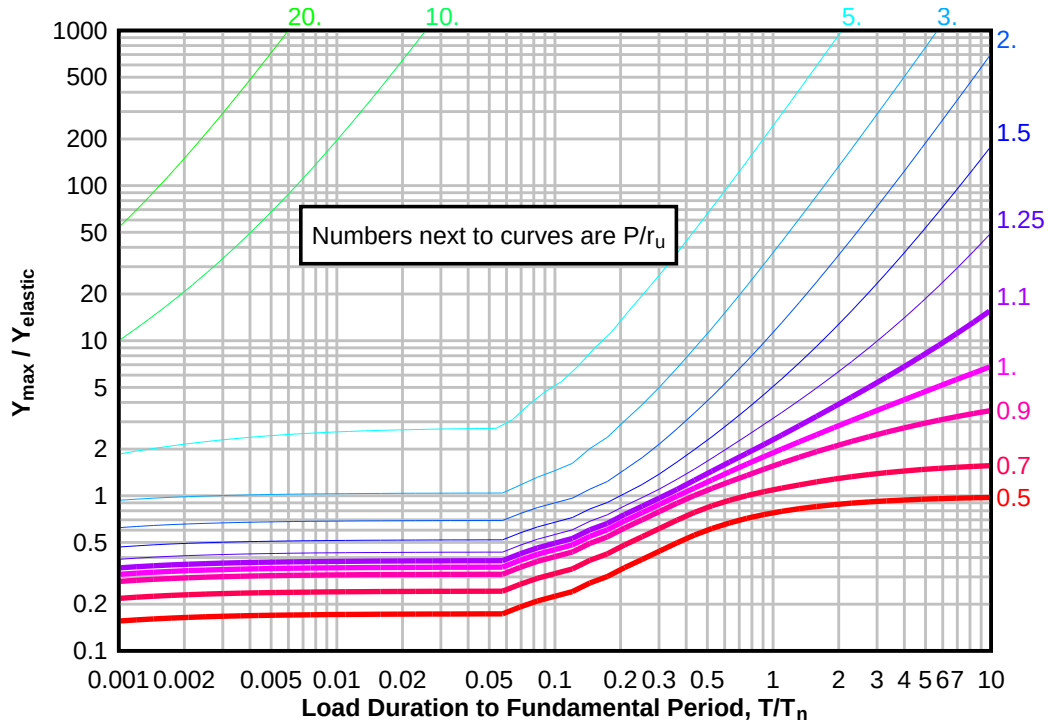


Figure 3-248(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.147, C2 = 1000)

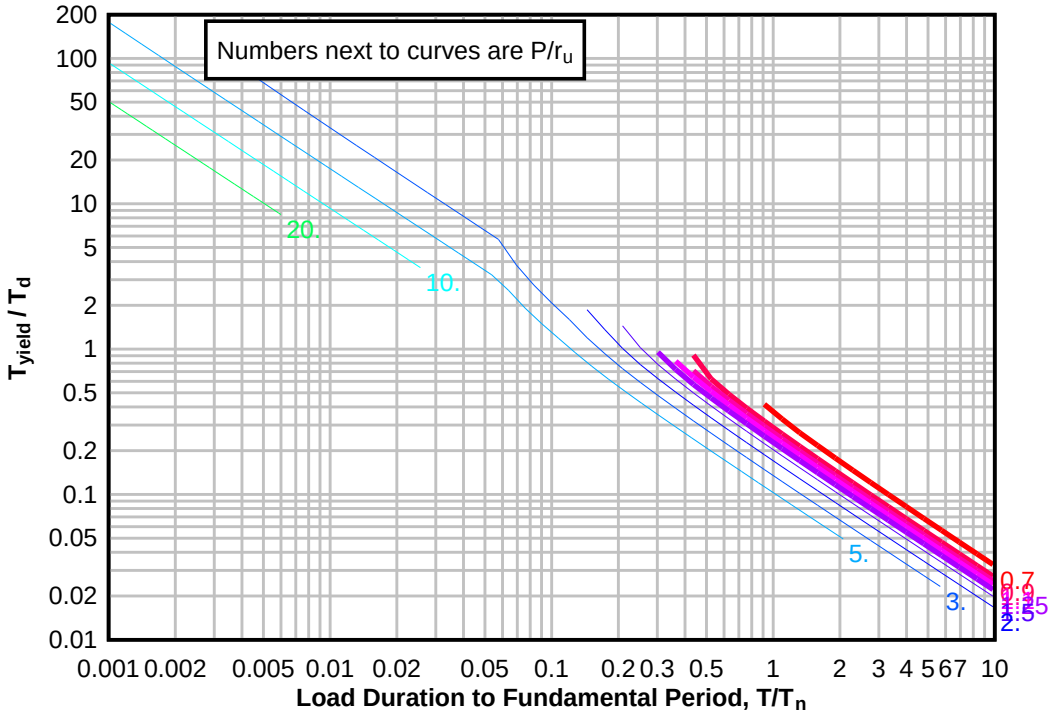


Figure 3-249(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.133, C_2 = 1000)

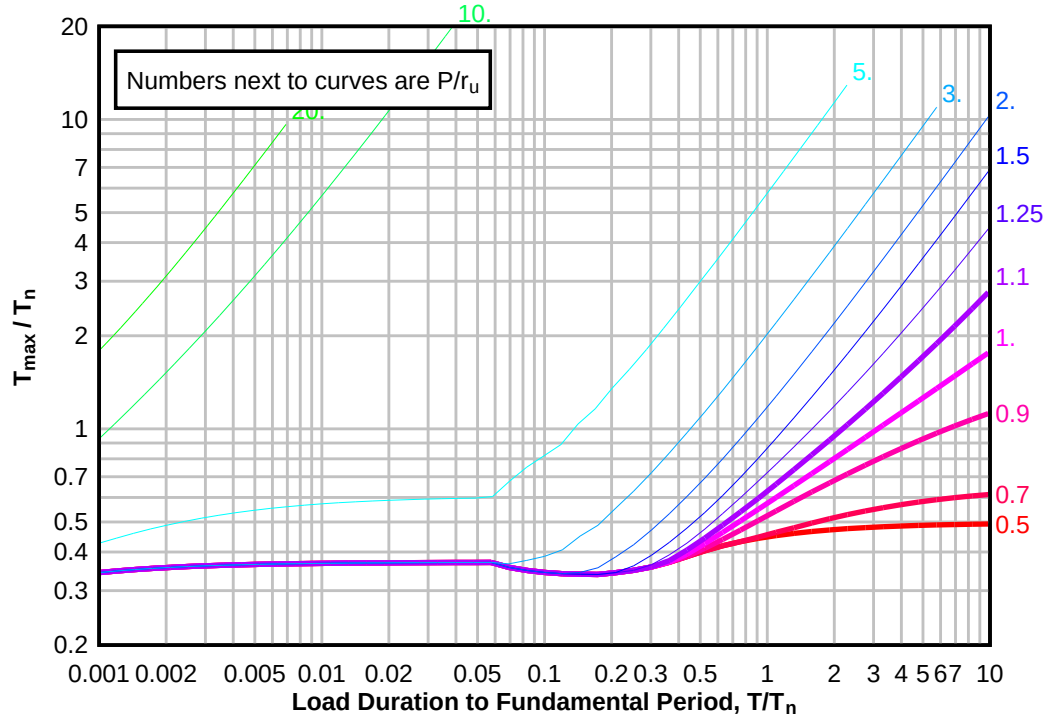


Figure 3-249(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.133, C2 = 1000)

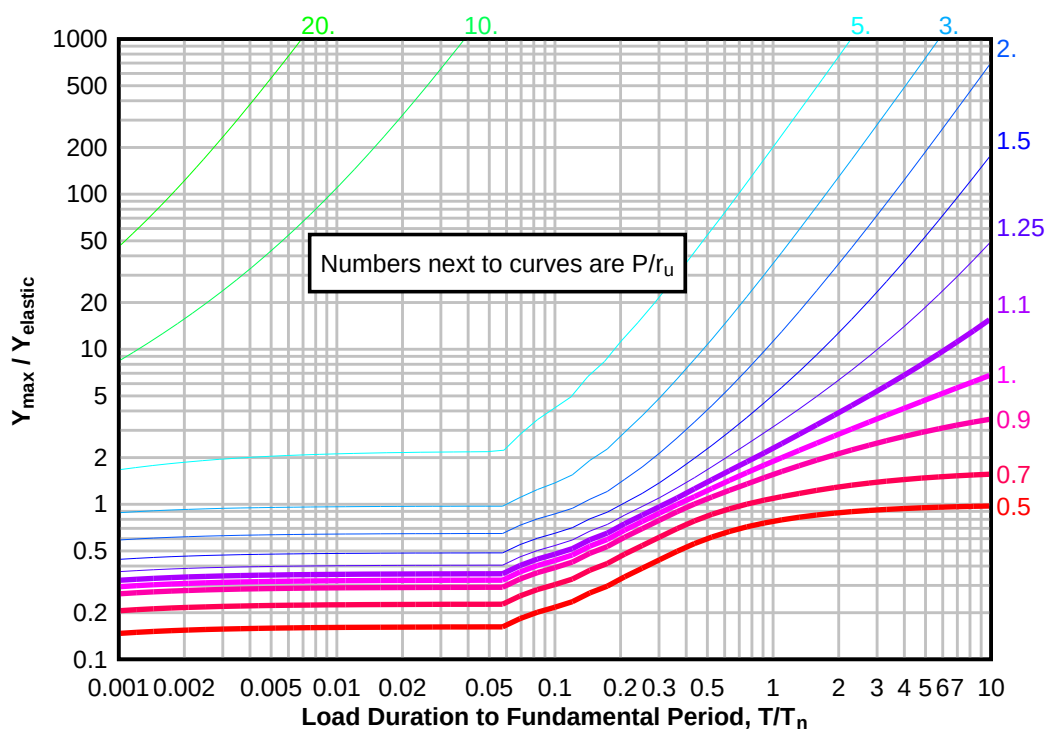


Figure 3-249(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.133, C2 = 1000)

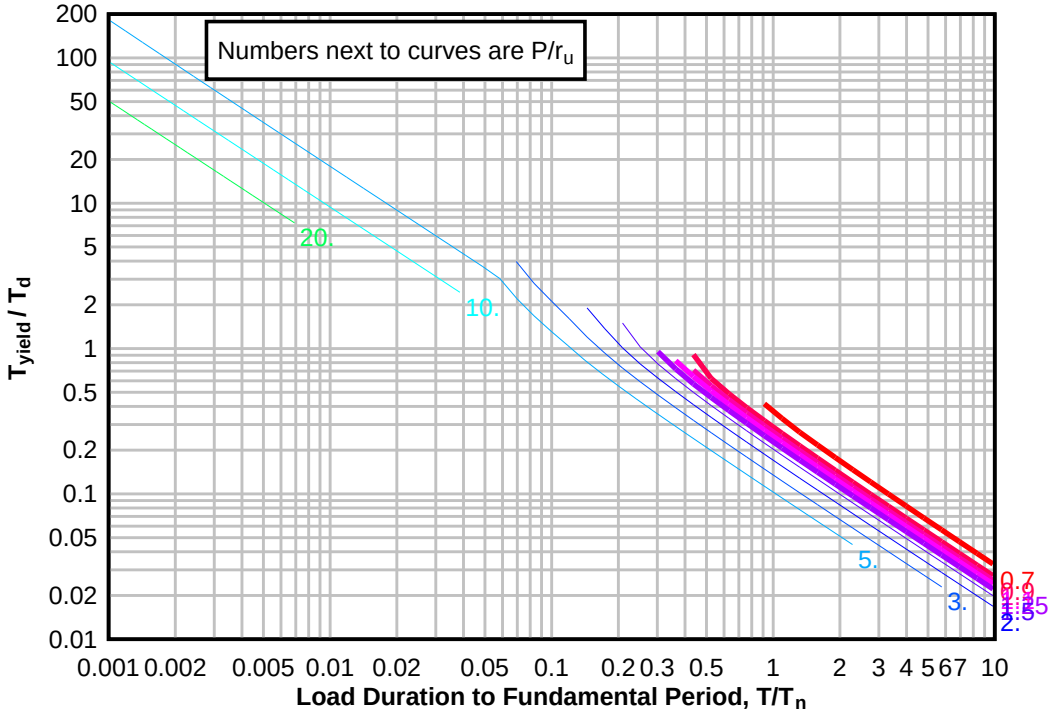


Figure 3-250(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.121, C_2 = 1000)

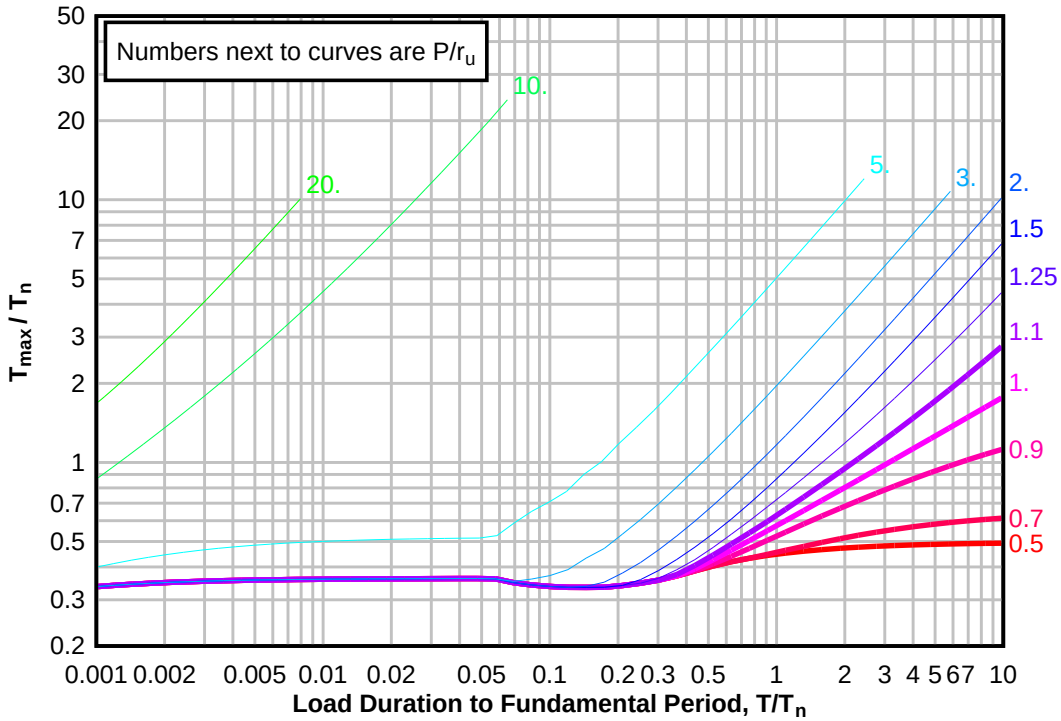


Figure 3-250(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.121, C2 = 1000)

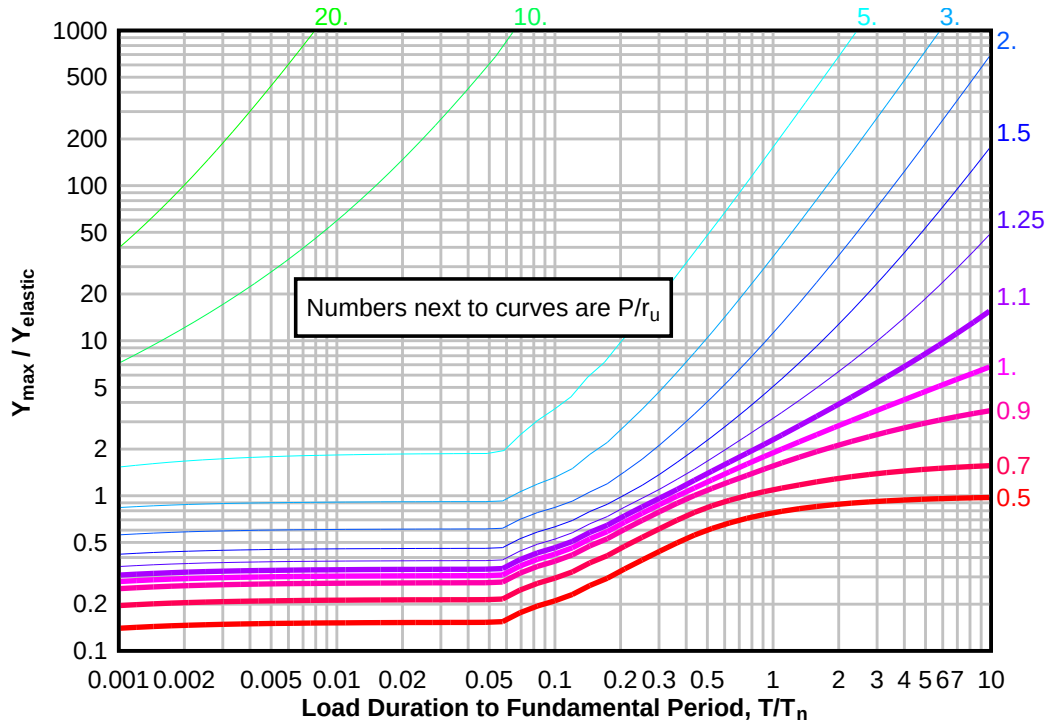


Figure 3-250(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.121, C2 = 1000)

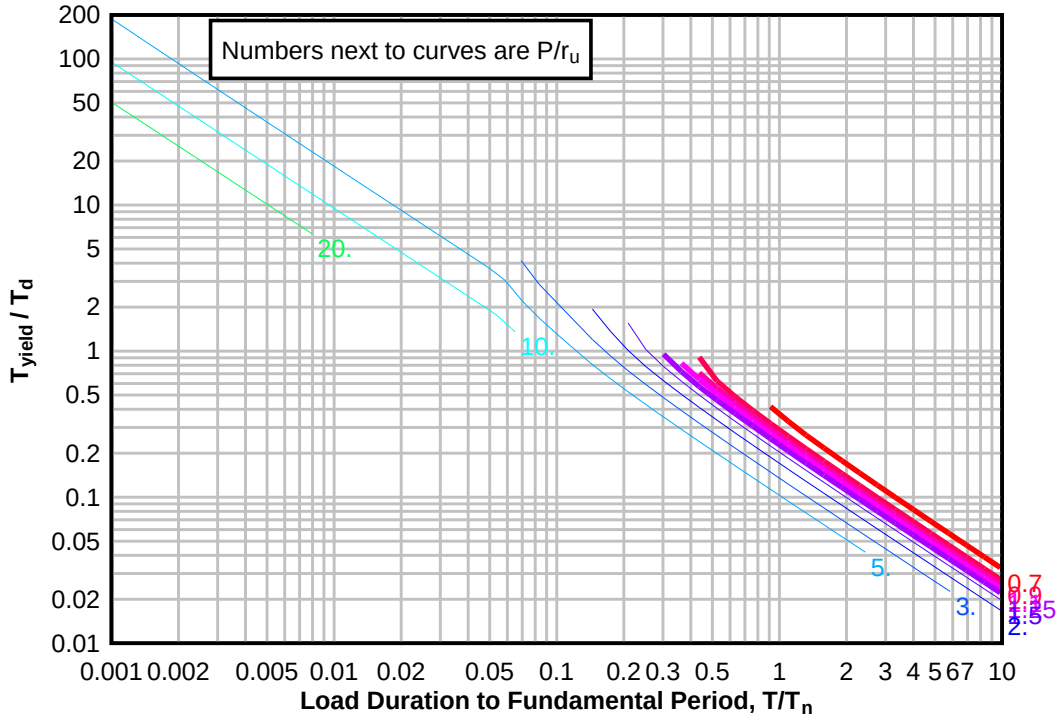


Figure 3-251(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.110, C_2 = 1000)

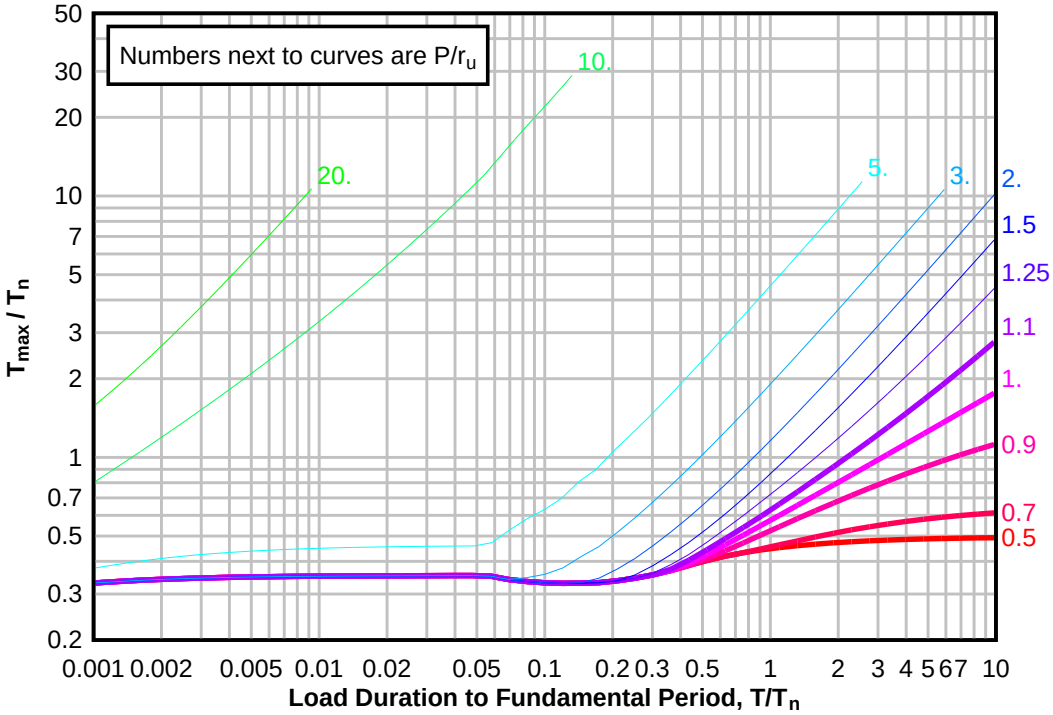


Figure 3-251(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.110, C2 = 1000)

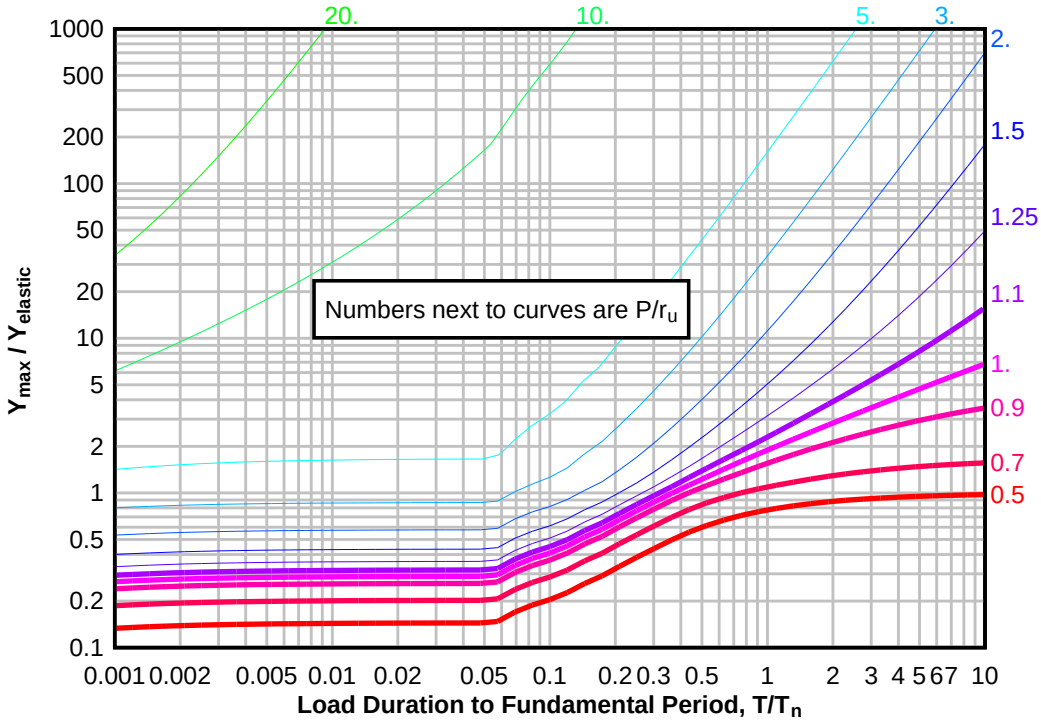


Figure 3-251(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.110, C2 = 1000)

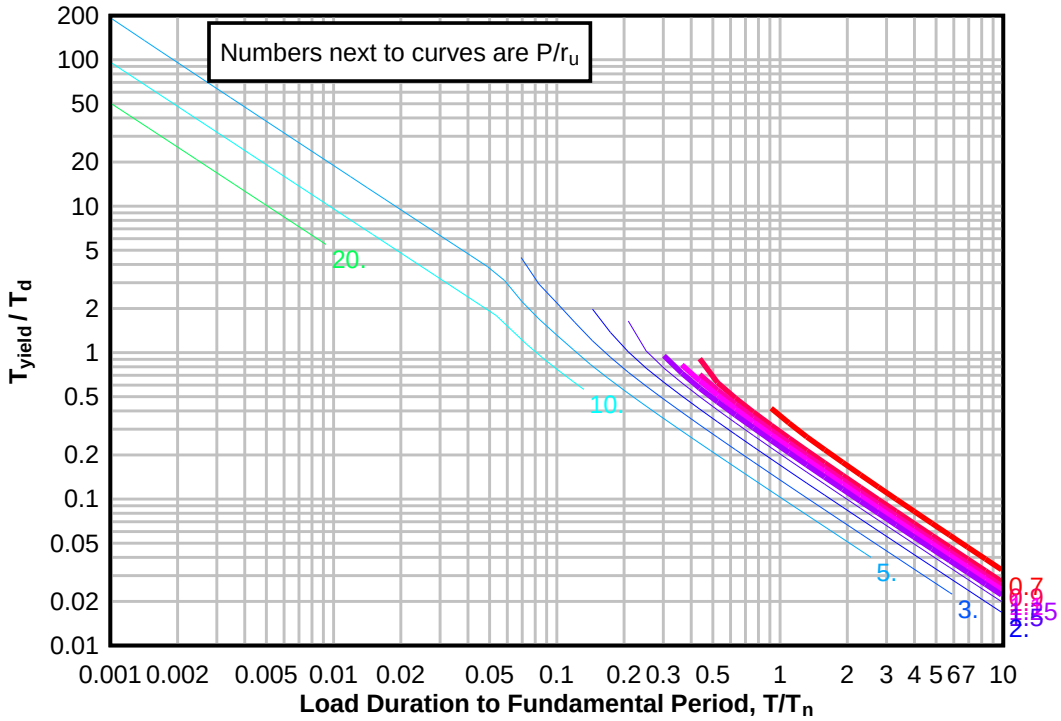


Figure 3-252(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.100, C_2 = 1000)

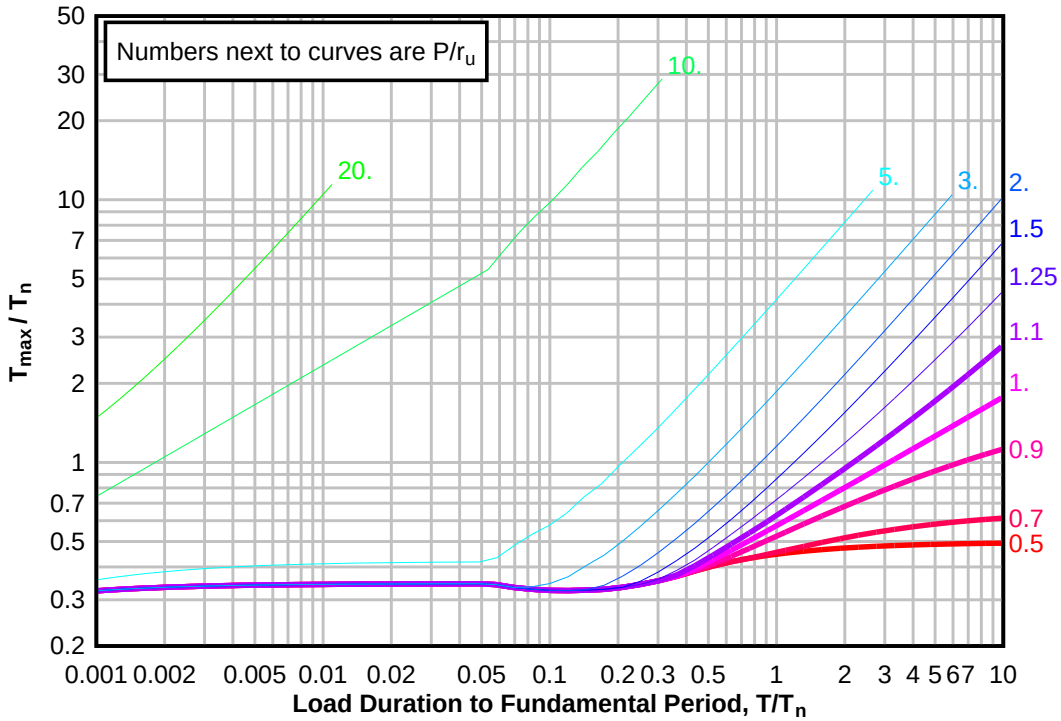


Figure 3-252(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.100, C2 = 1000)

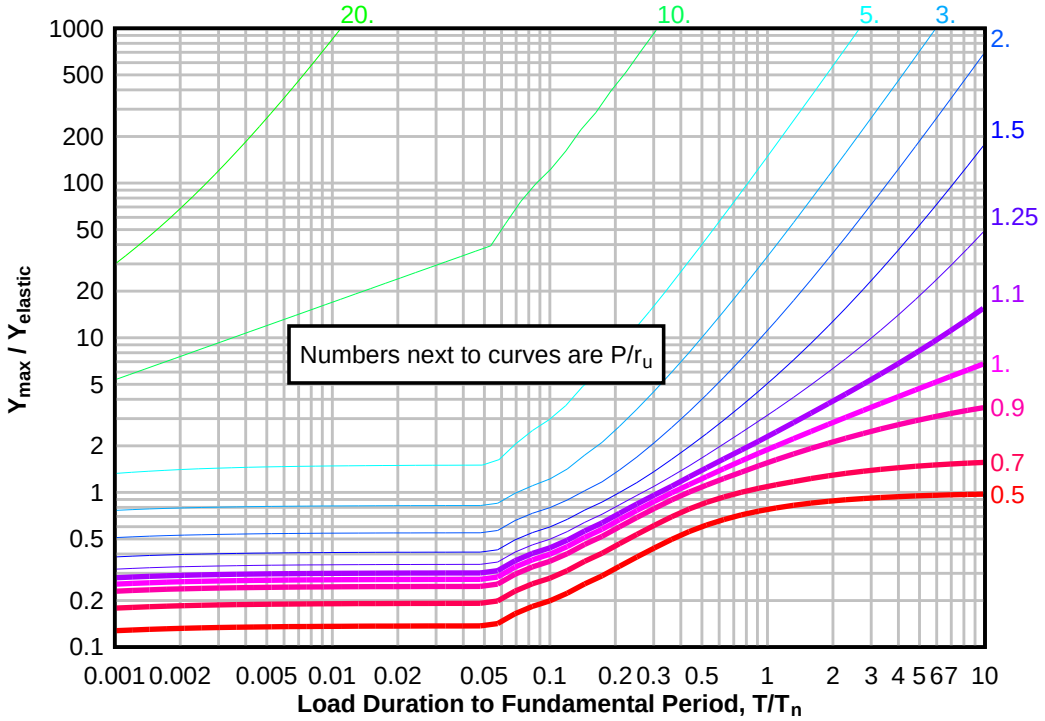


Figure 3-252(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.100, C2 = 1000)

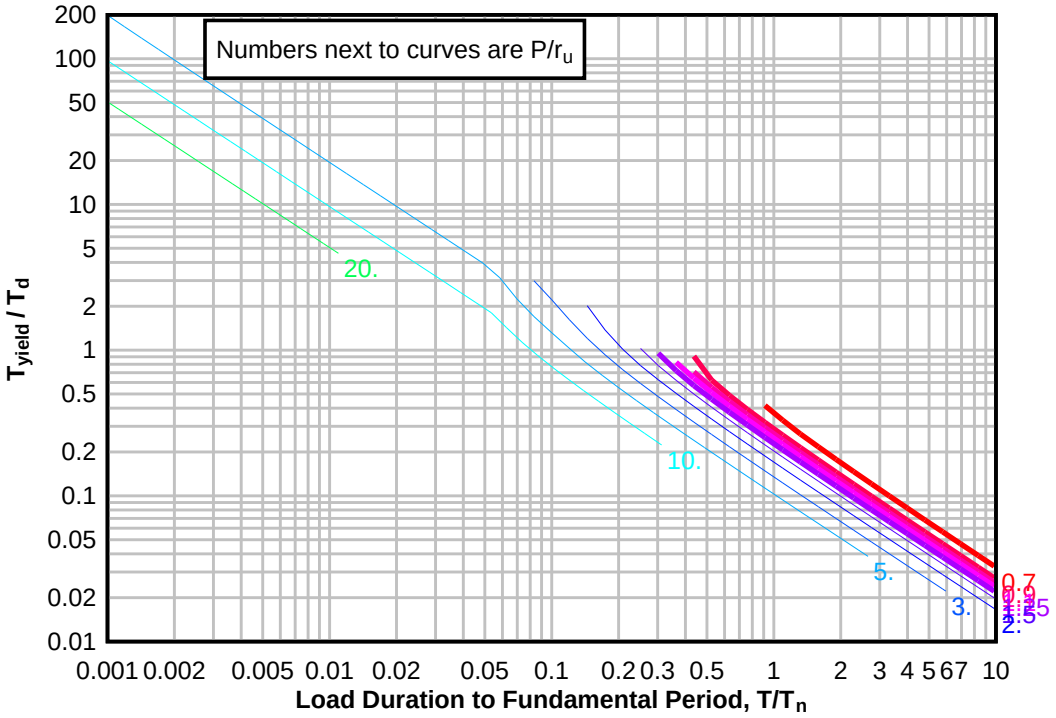


Figure 3-253(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.091, C_2 = 1000)

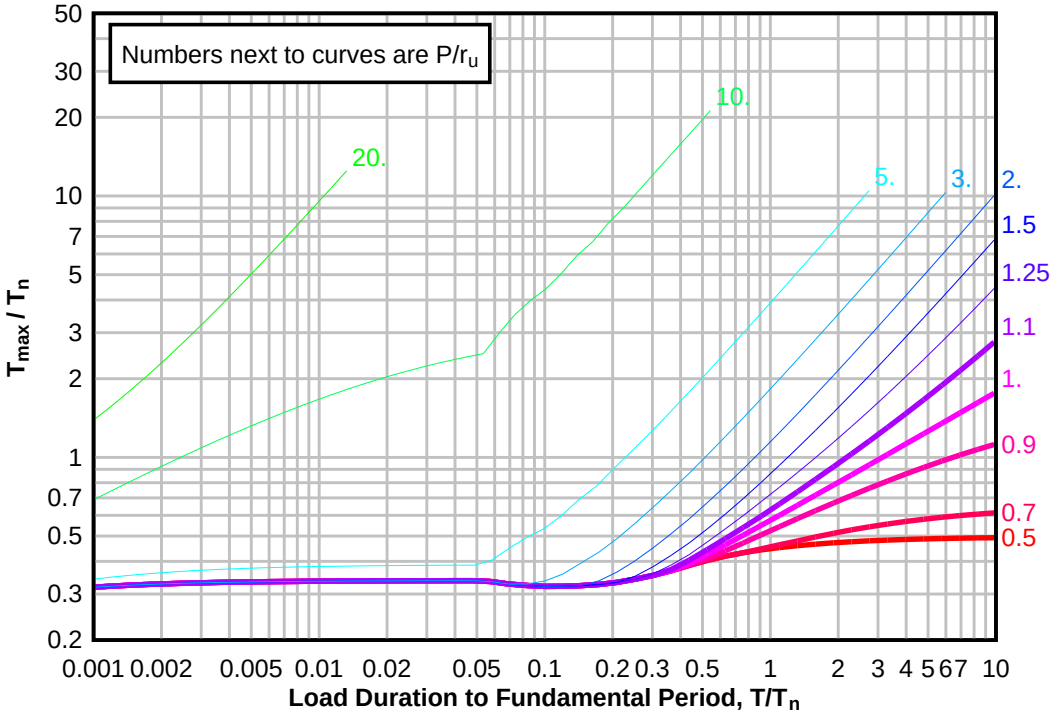


Figure 3-253(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.091, C2 = 1000)

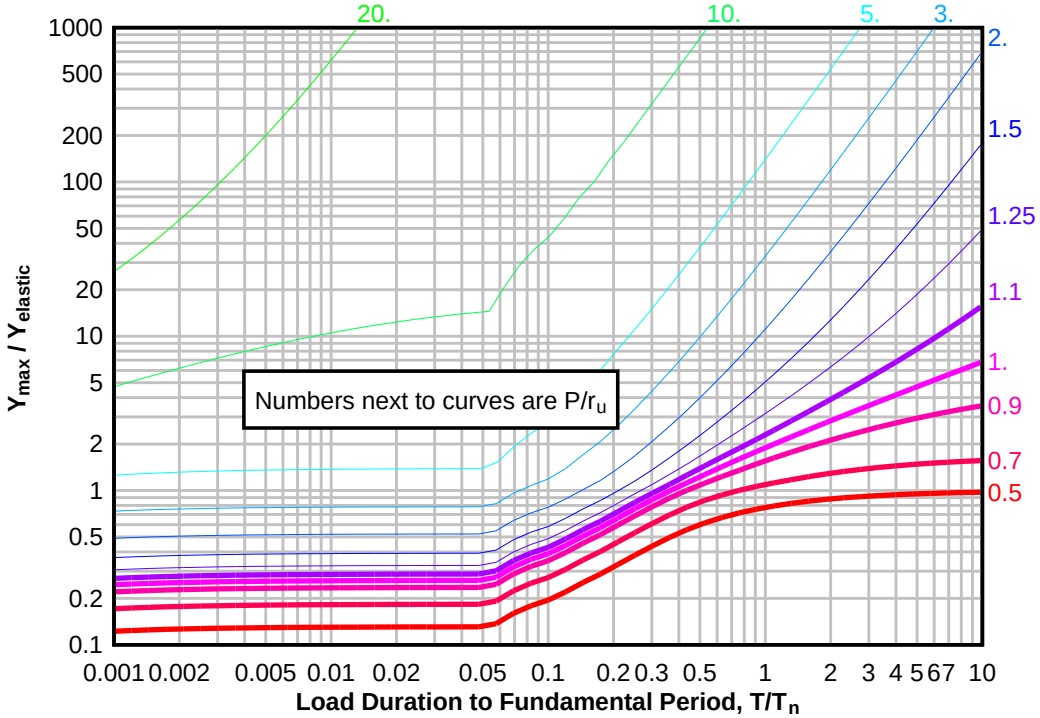


Figure 3-253(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.091, C2 = 1000)

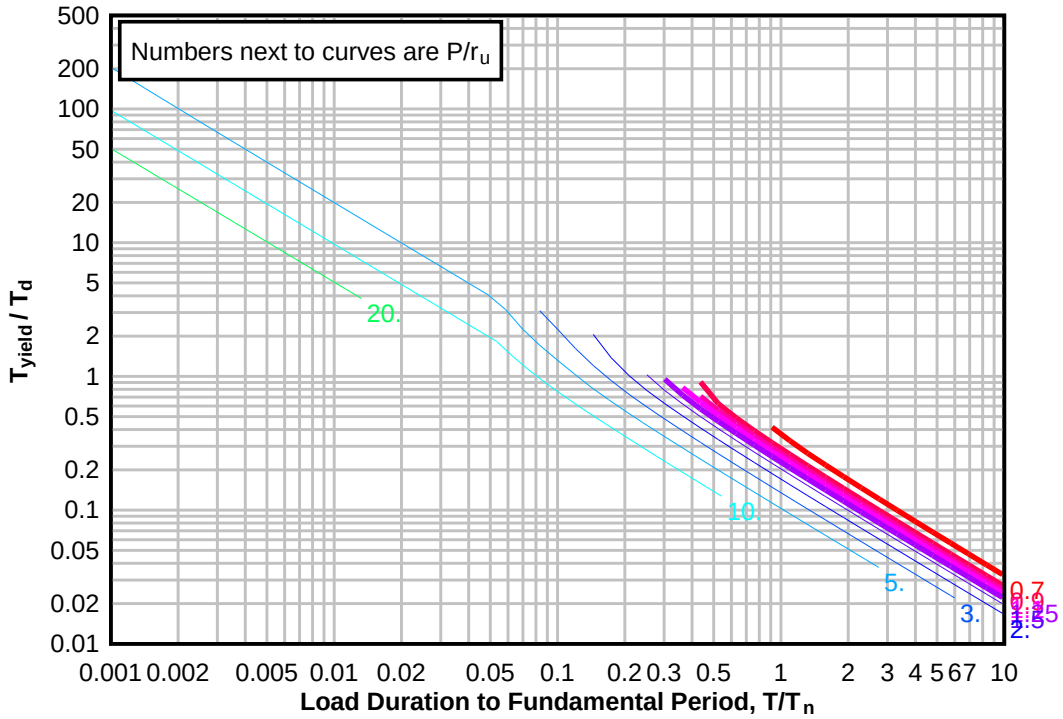


Figure 3-254(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.083, C_2 = 1000)

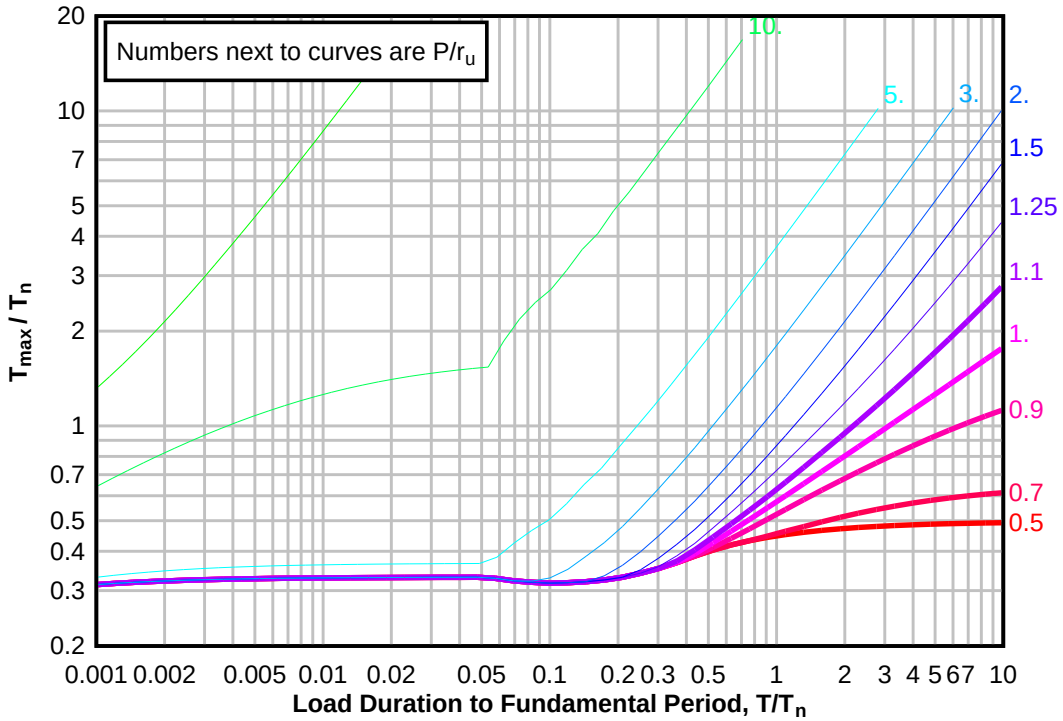


Figure 3-254(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.083, C2 = 1000)

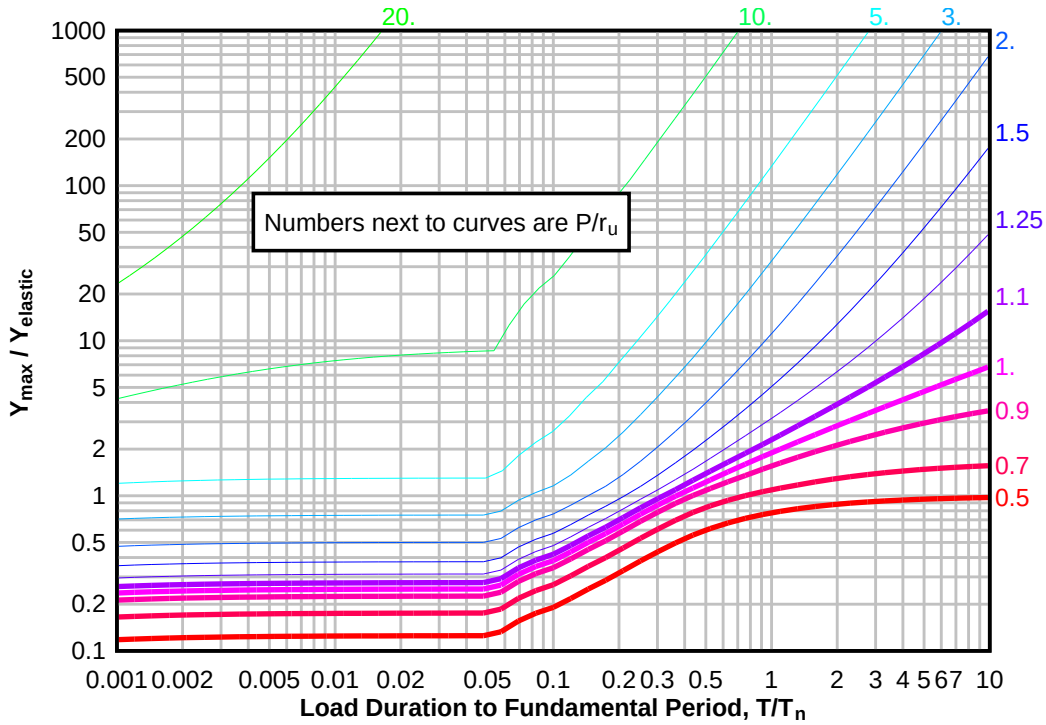


Figure 3-254(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.083, C2 = 1000)

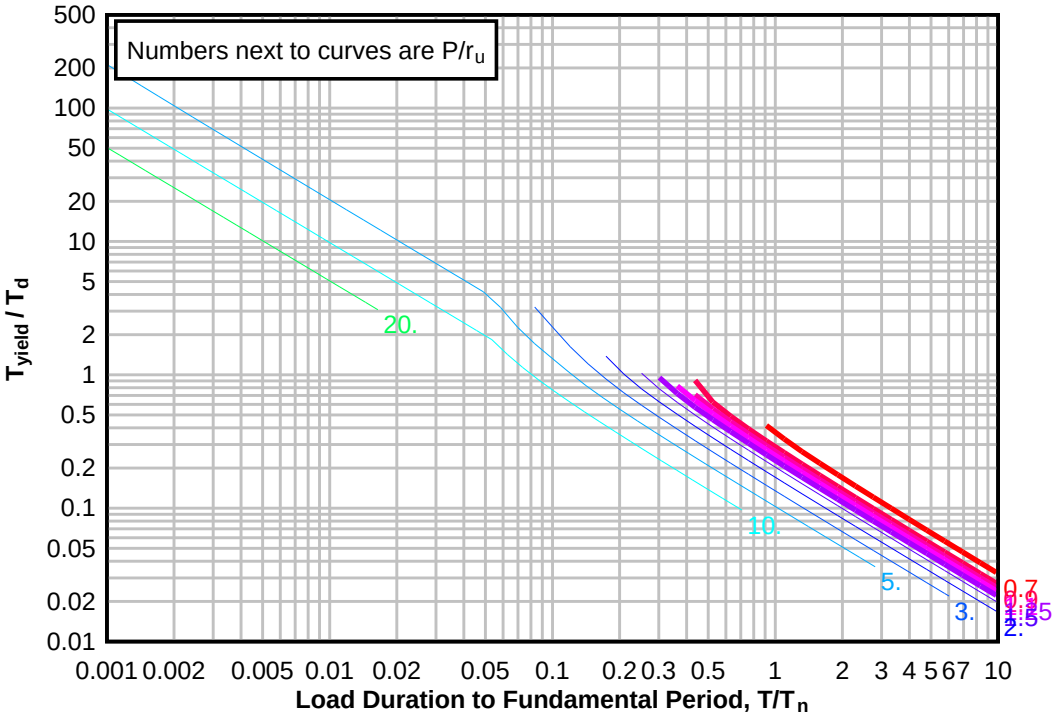


Figure 3-255(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.075, C_2 = 1000)

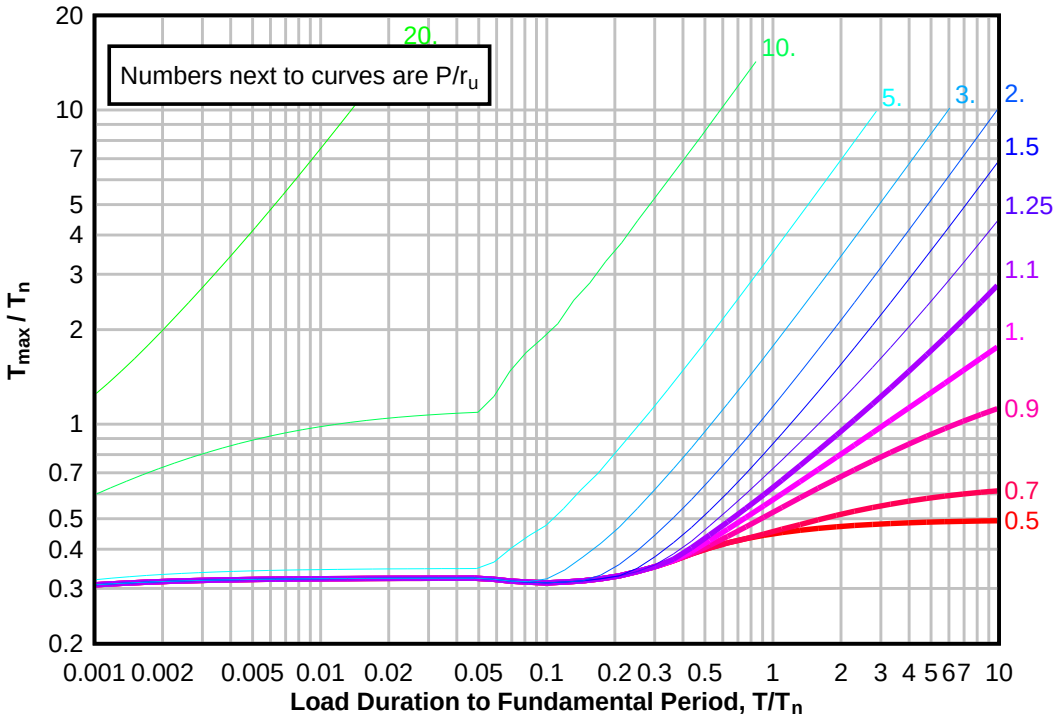


Figure 3-255(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.075, C2 = 1000)

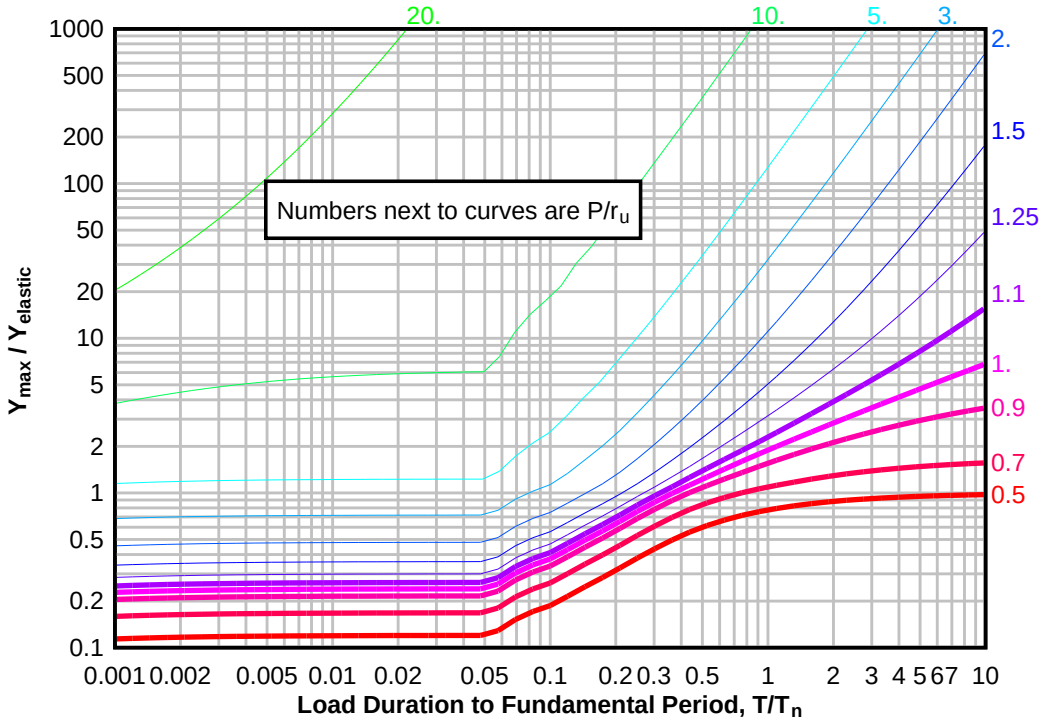


Figure 3-255(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.075, C2 = 1000)

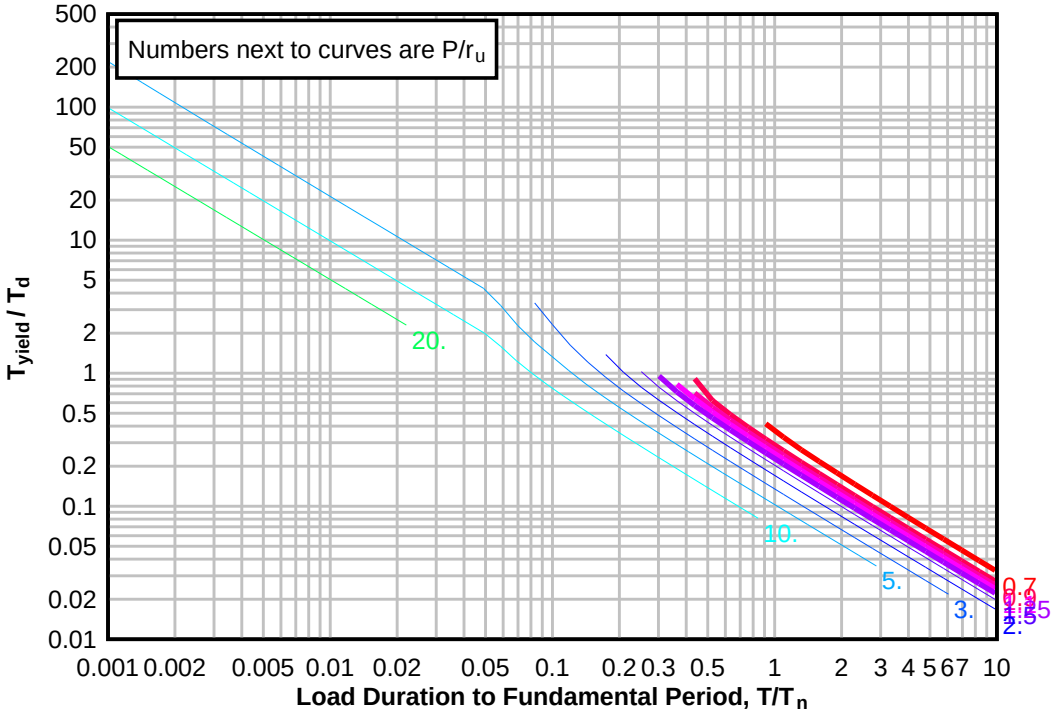


Figure 3-256(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.068, C_2 = 1000)

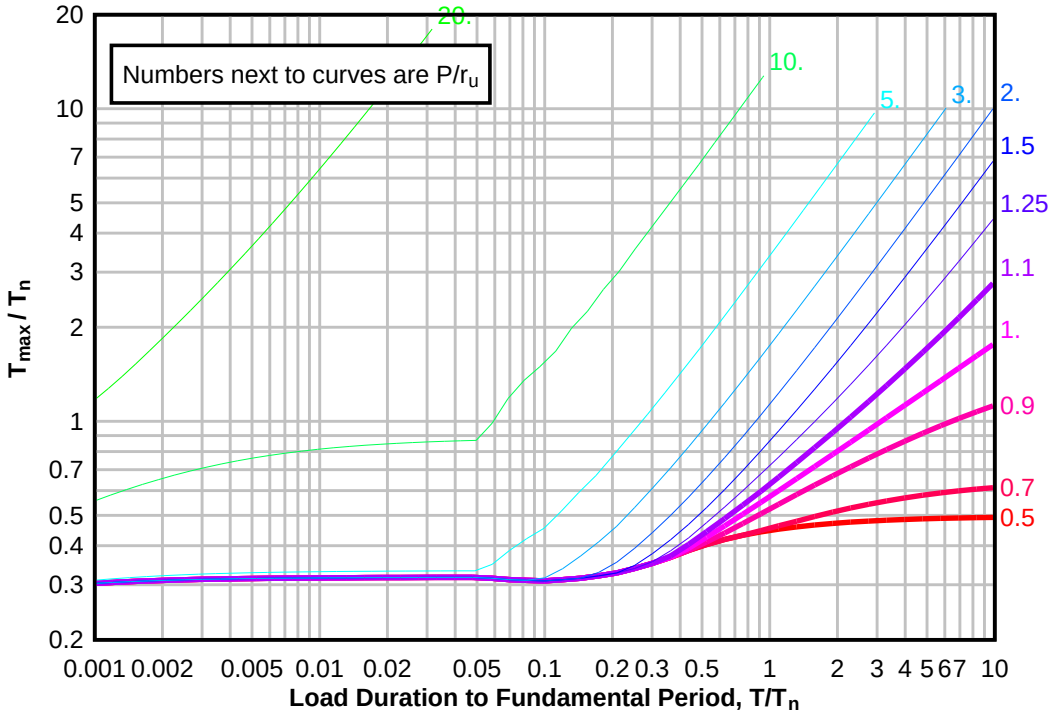


Figure 3-256(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.068, C2 = 1000)

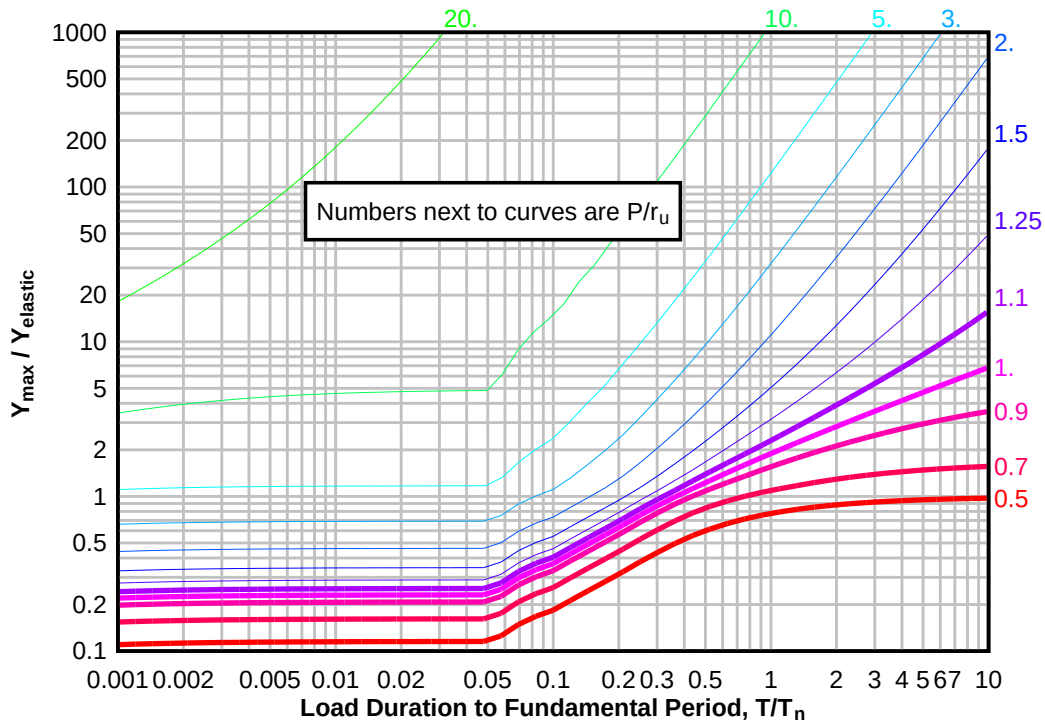


Figure 3-256(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.068, C2 = 1000)

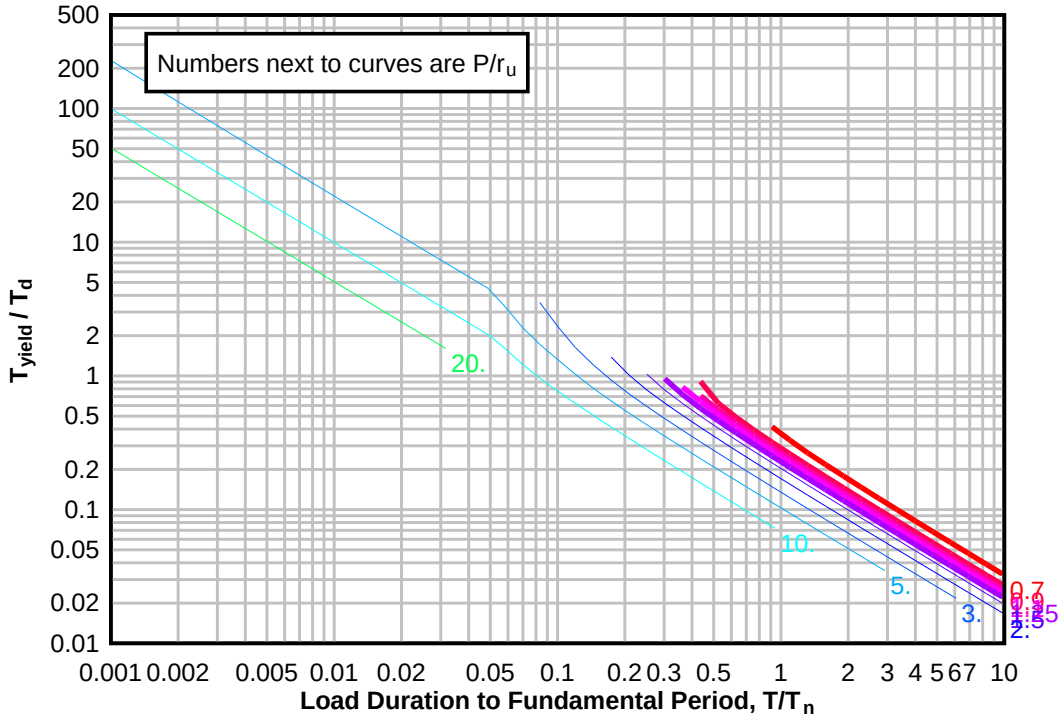


Figure 3-257(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.056, C_2 = 1000)

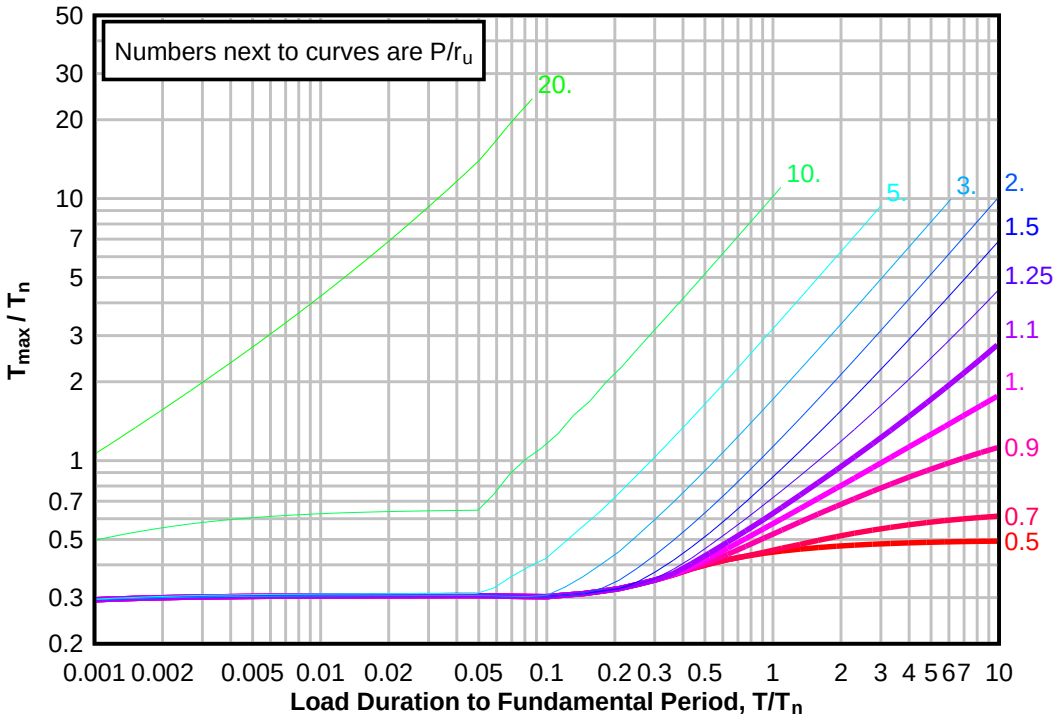


Figure 3-257(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.056, C2 = 1000)

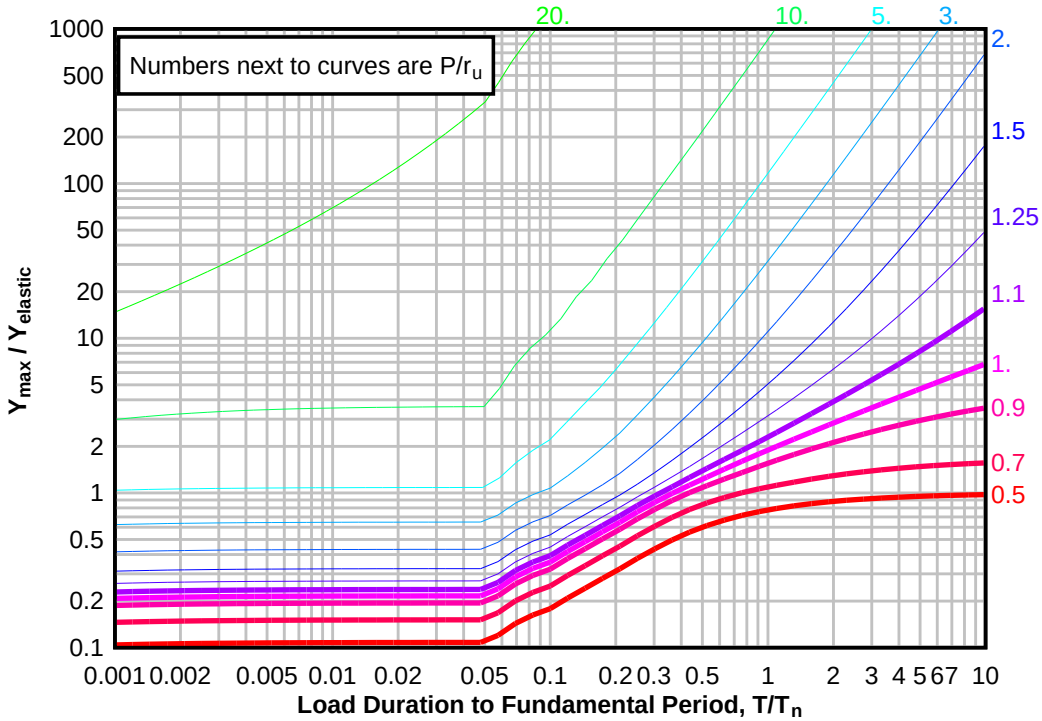


Figure 3-257(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.056, C2 = 1000)

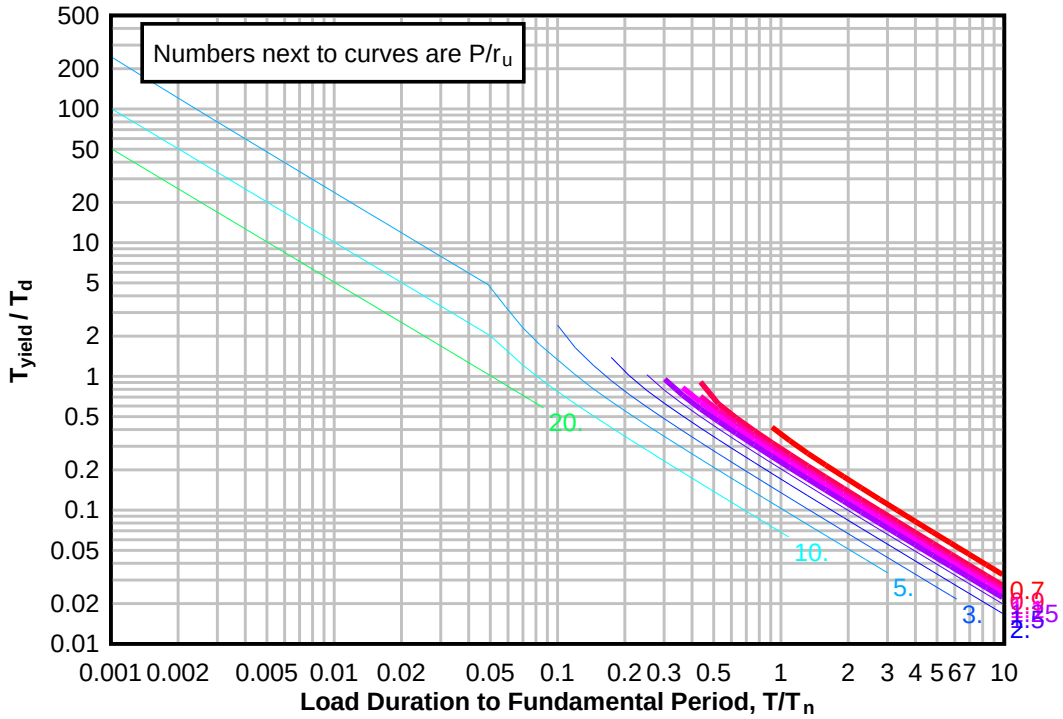


Figure 3-258(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.046, C_2 = 1000)

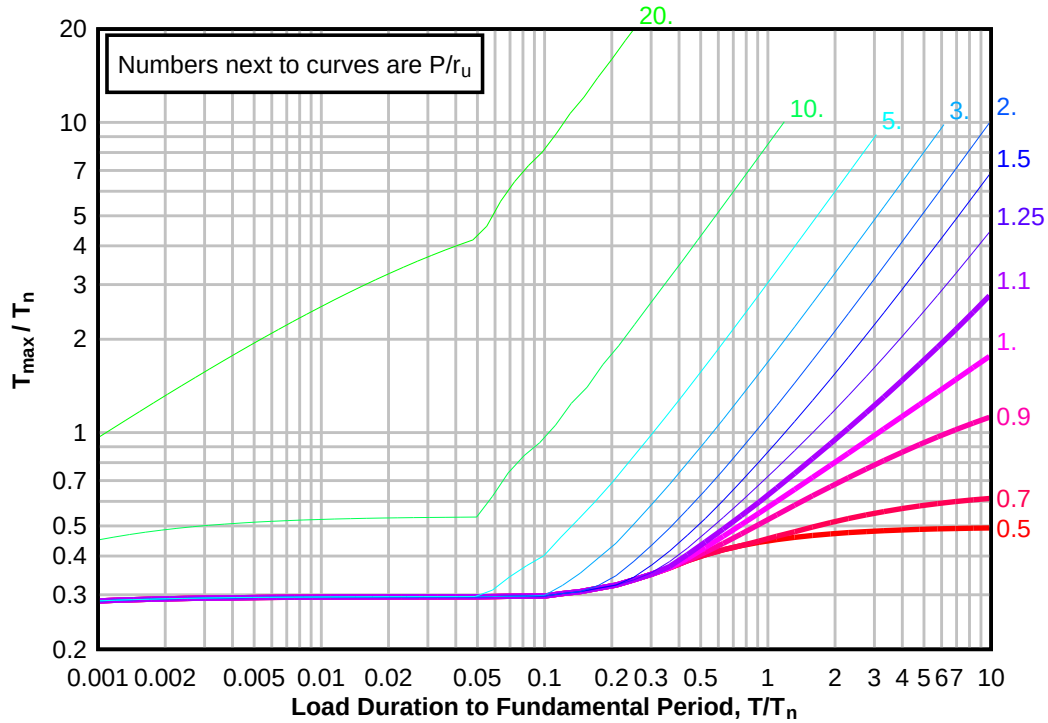


Figure 3-258(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.046, C2 = 1000)

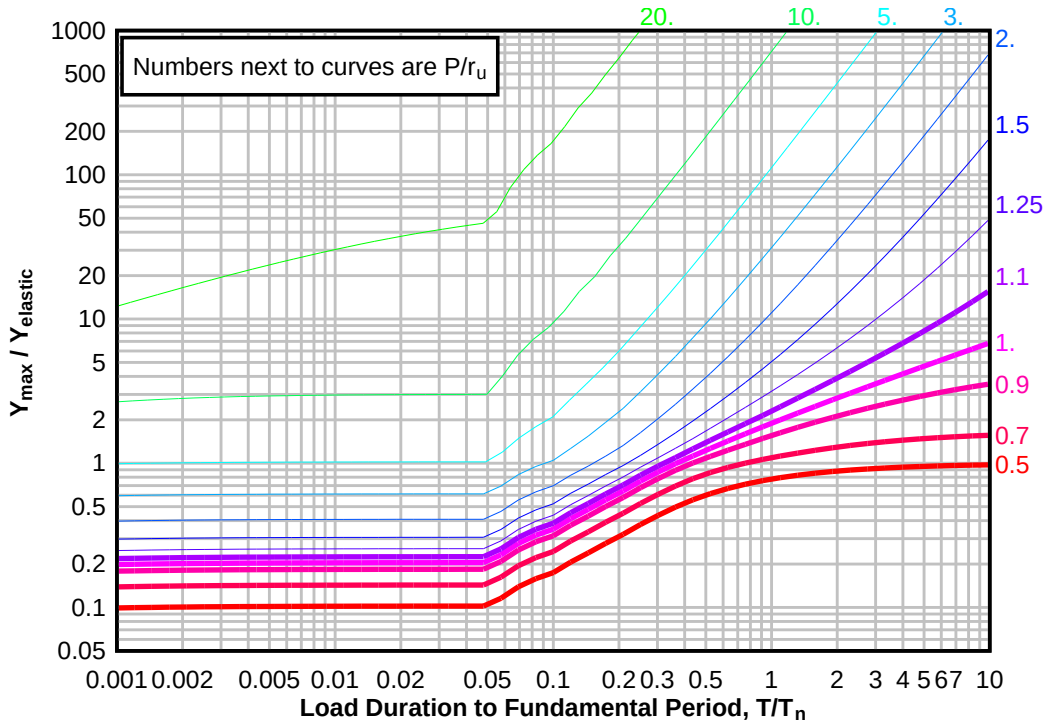


Figure 3-258(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.046, C2 = 1000)

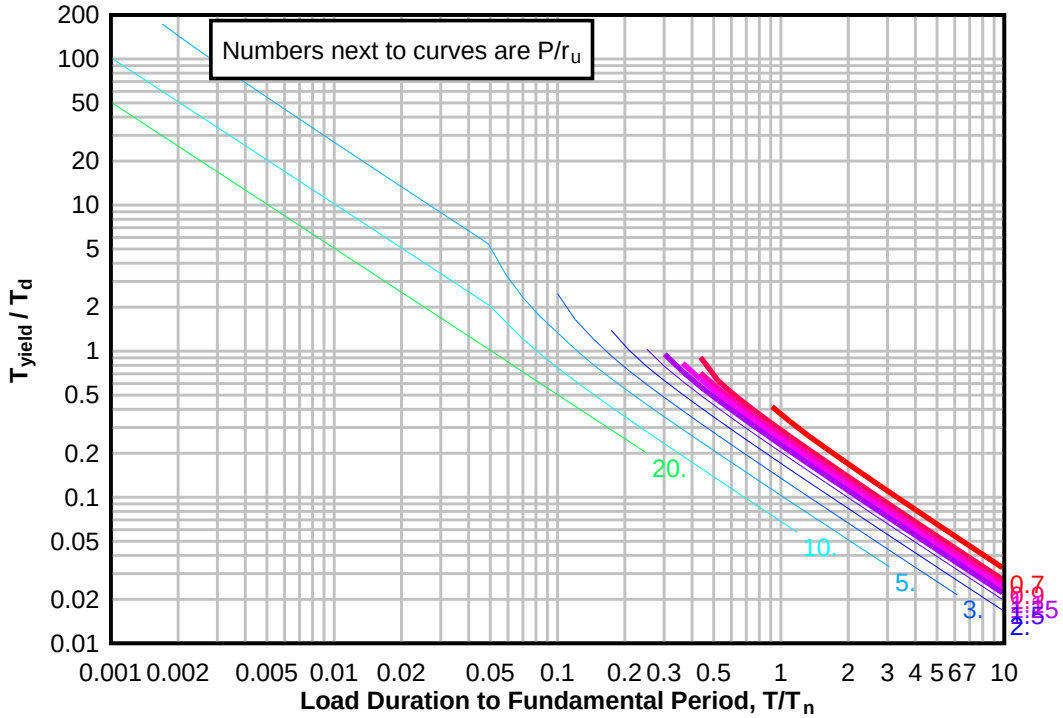


Figure 3-259(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.042, C_2 = 1000)

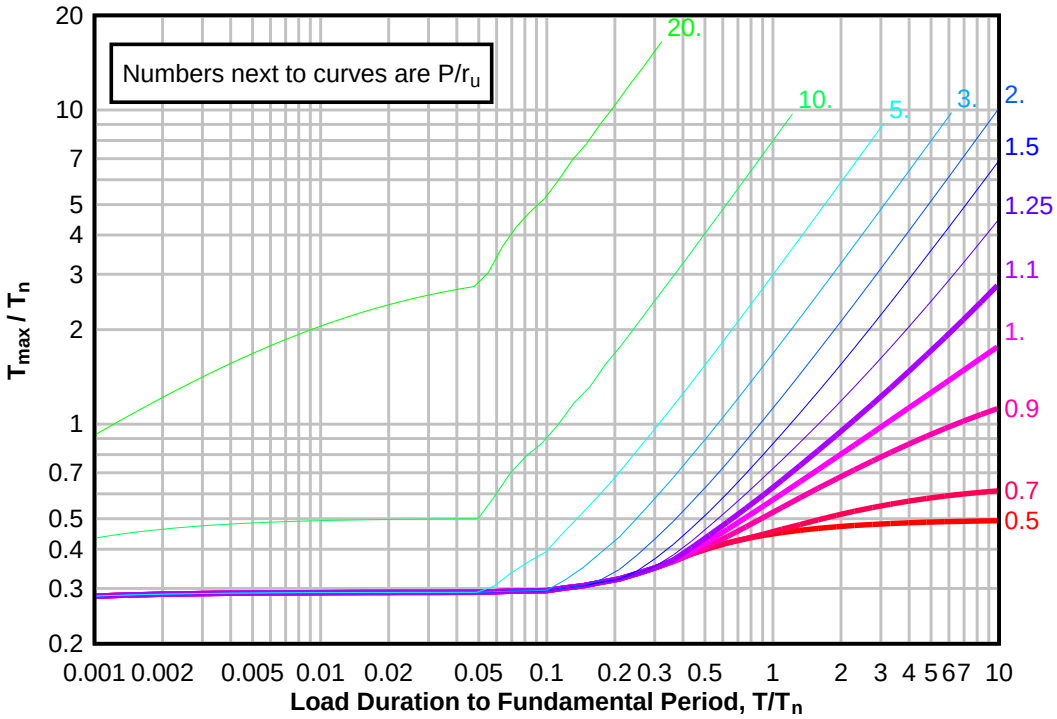


Figure 3-259(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.042, C2 = 1000)

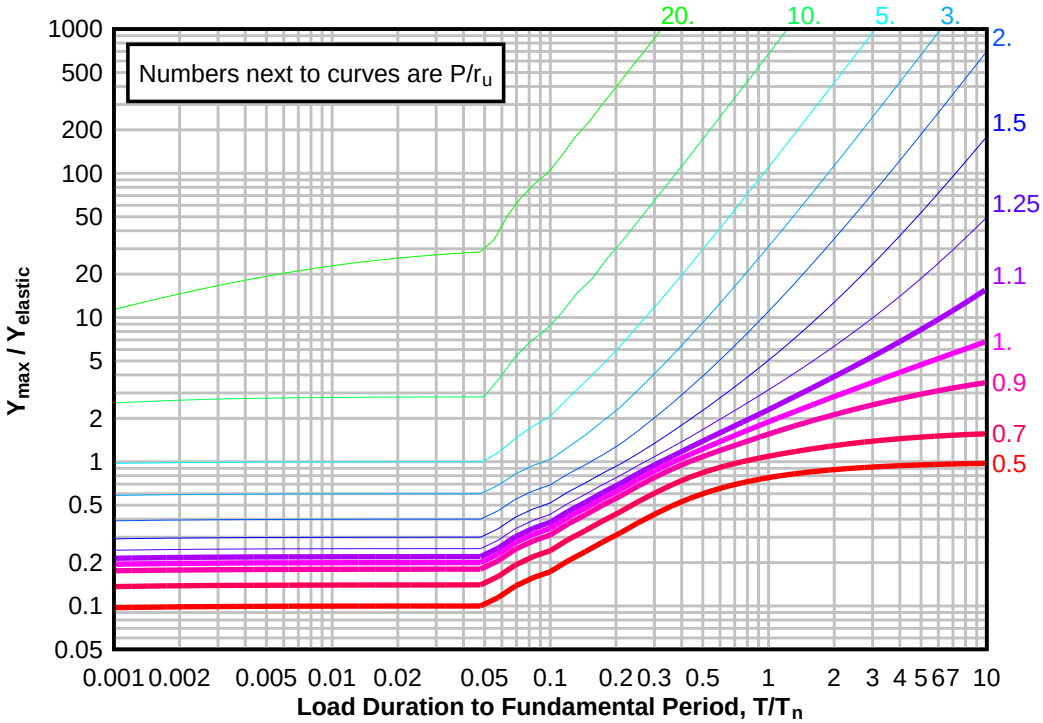


Figure 3-259(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.042, C2 = 1000)

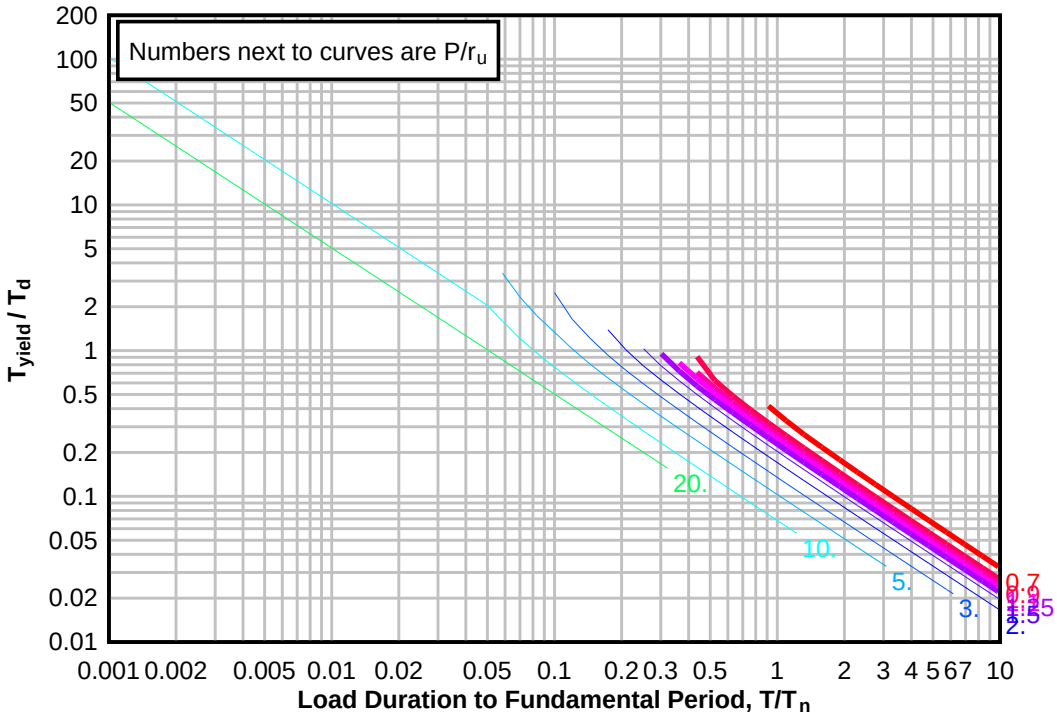


Figure 3-260(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.032, C_2 = 1000)

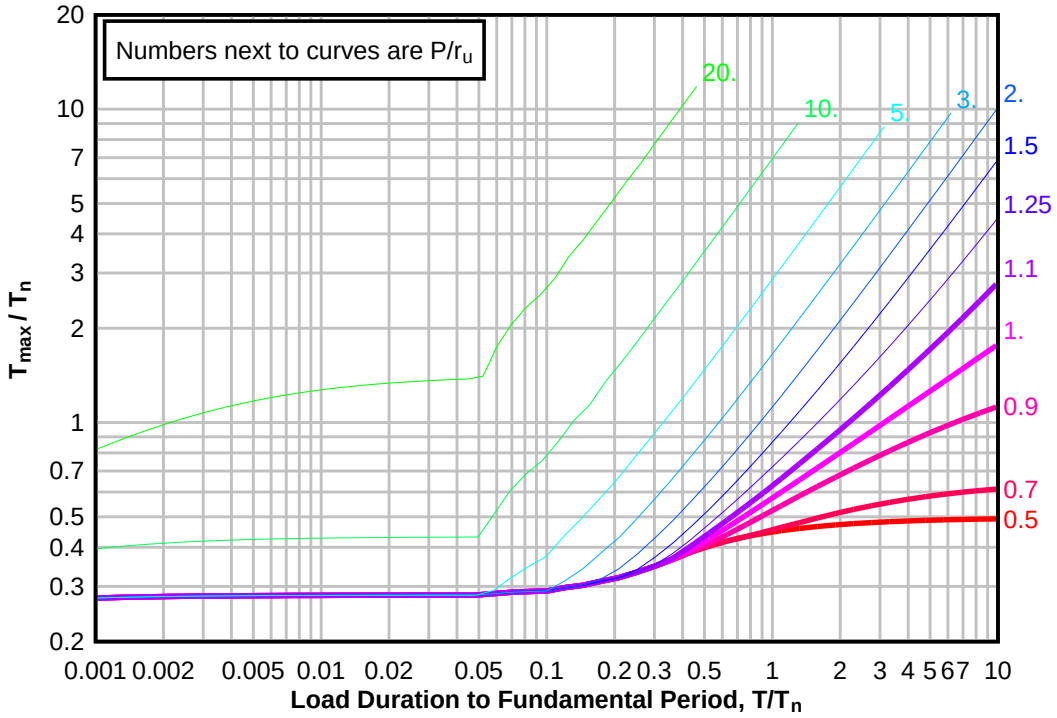


Figure 3-260(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.032, C2 = 1000)

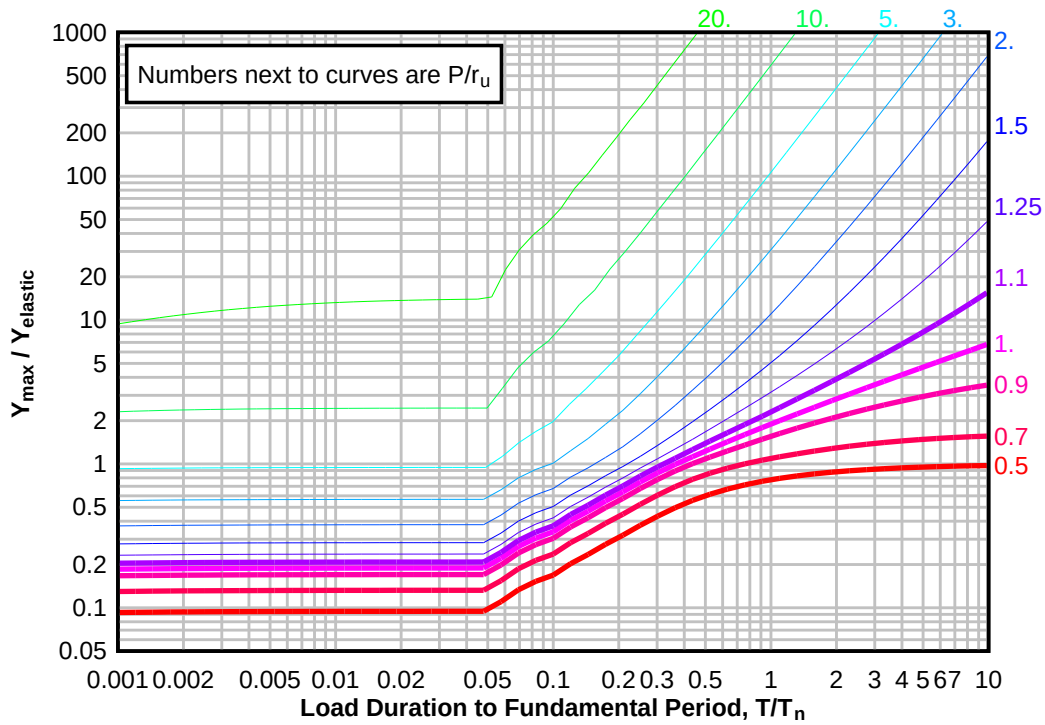


Figure 3-260(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.032, C2 = 1000)

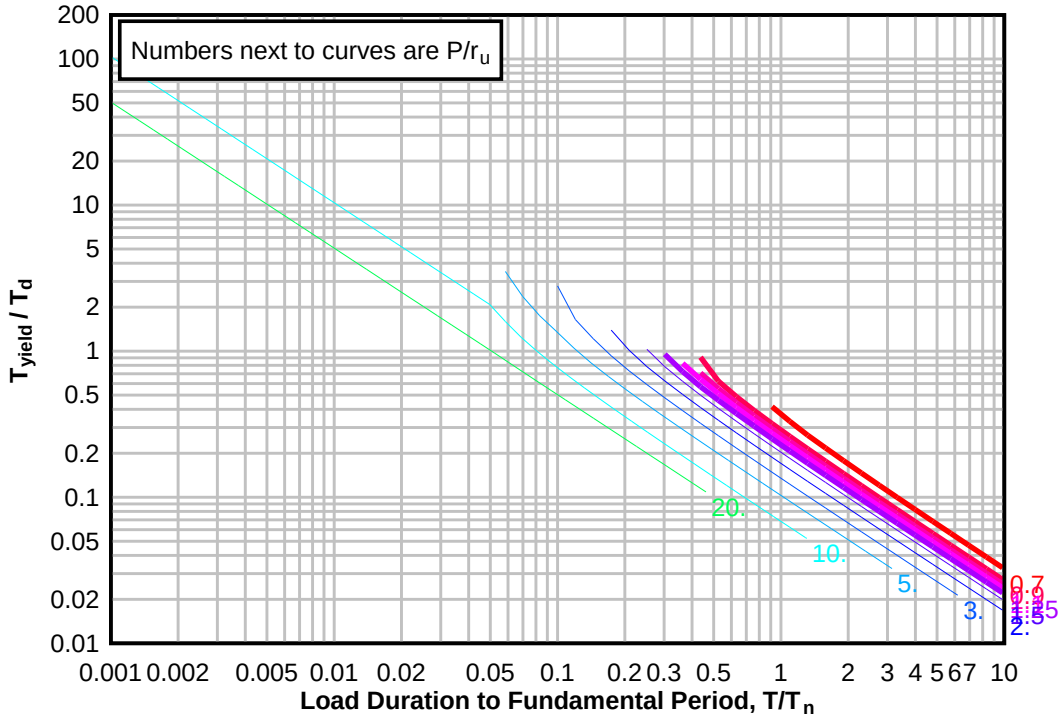


Figure 3-261(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.026, C_2 = 1000)

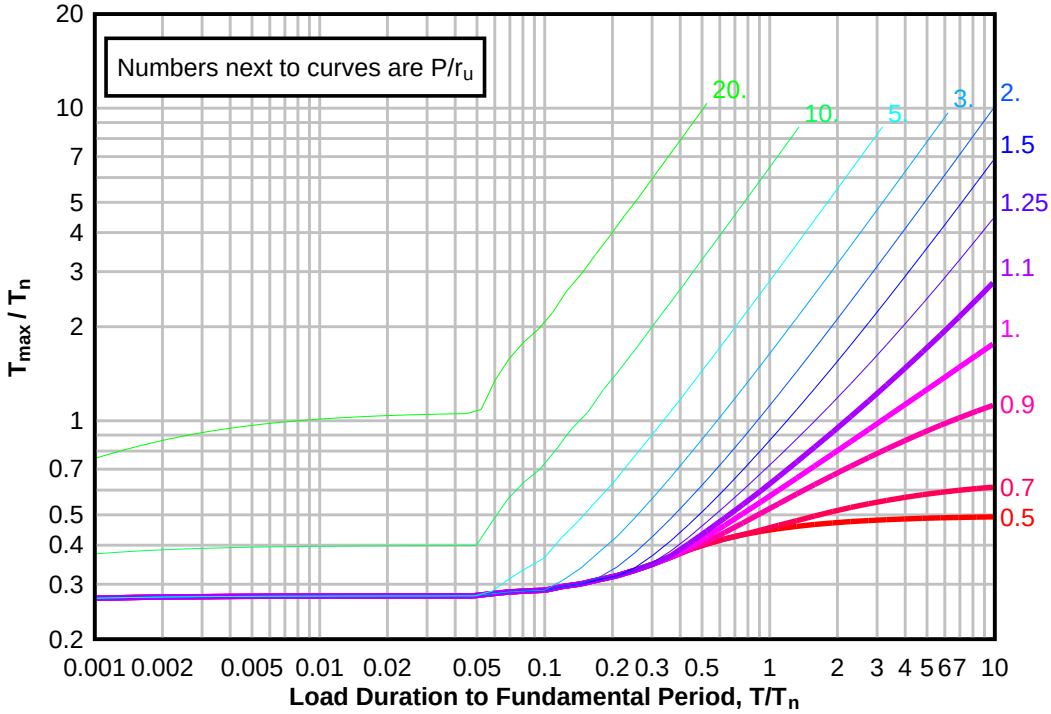


Figure 3-261(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.026, C2 = 1000)

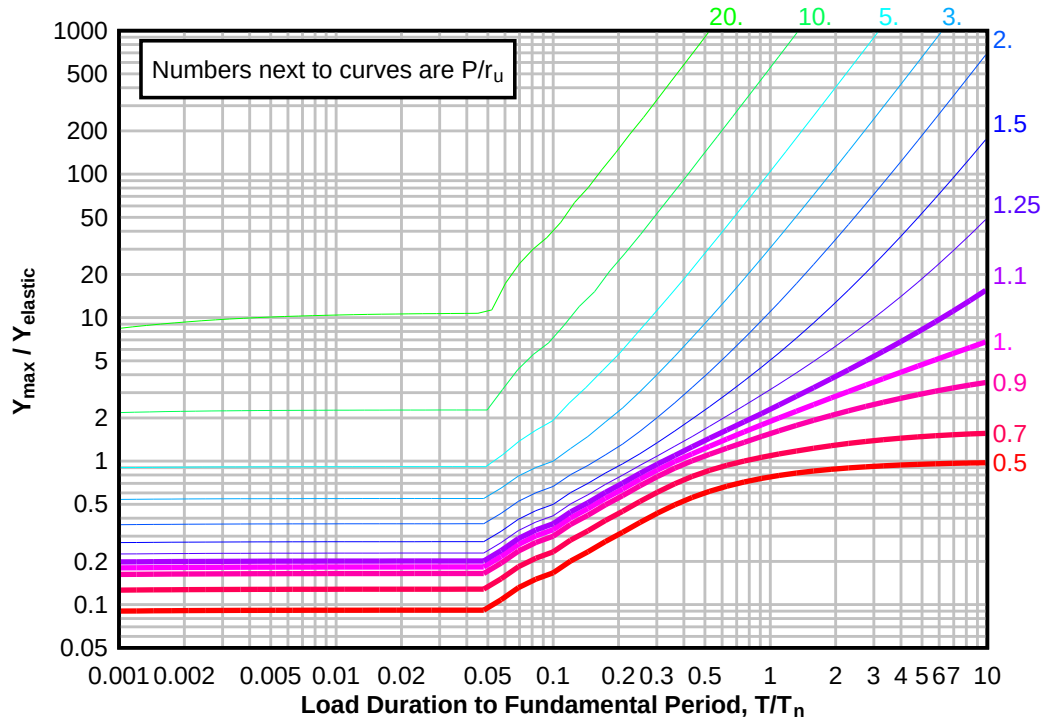


Figure 3-261(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.026, C2 = 1000)

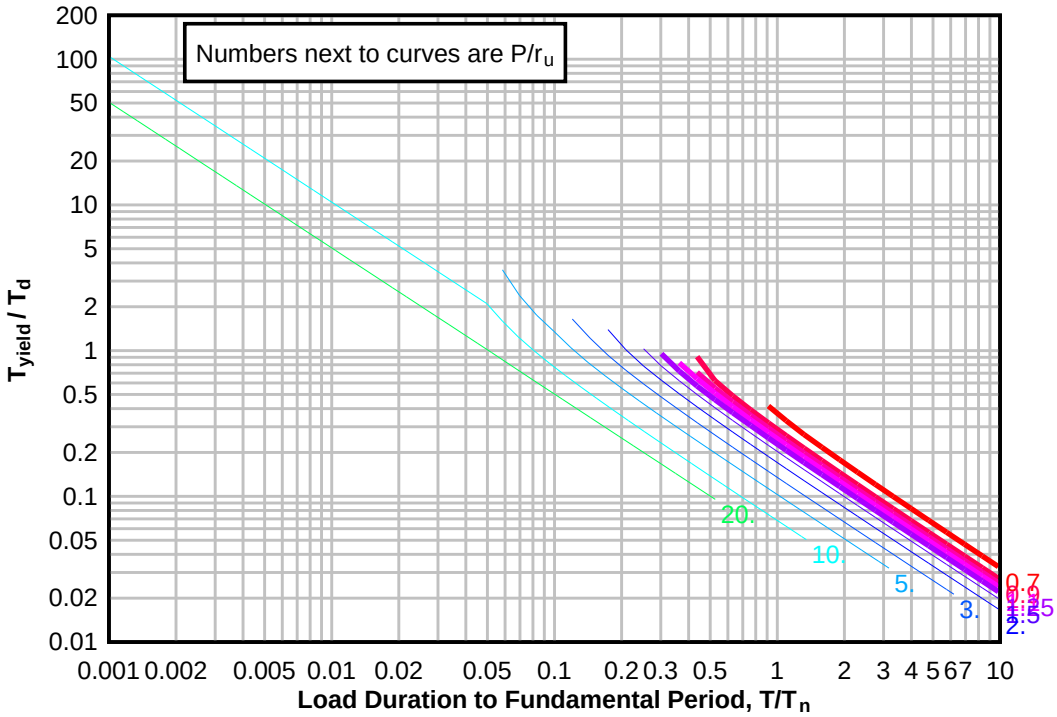


Figure 3-262(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.022, C_2 = 1000)

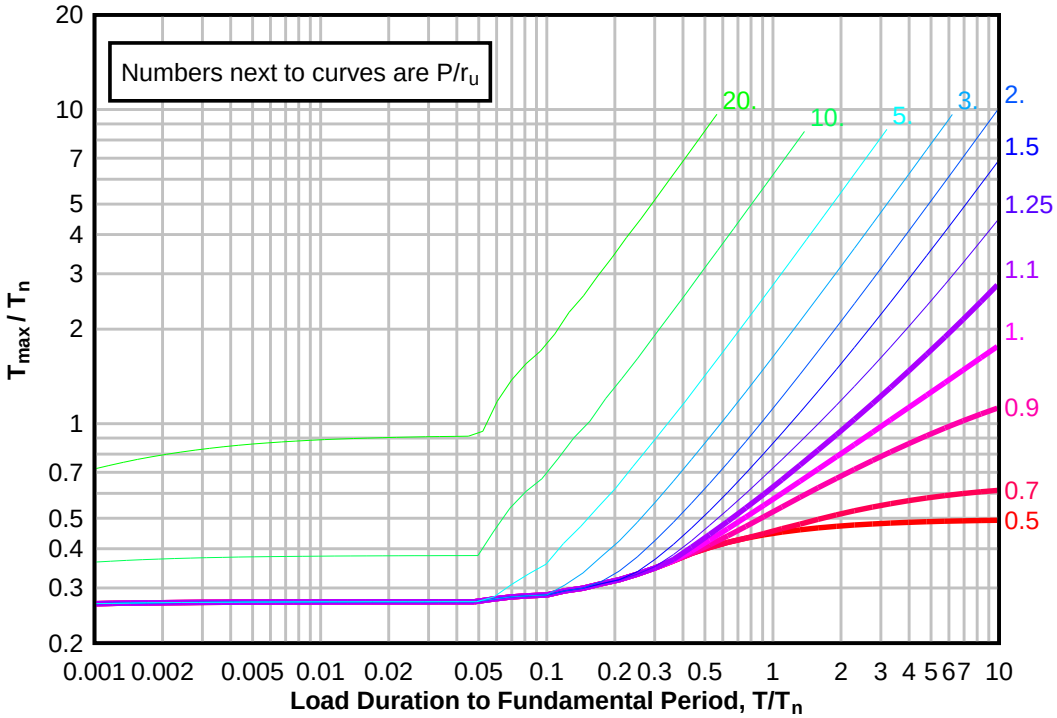


Figure 3-262(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.022, C2 = 1000)

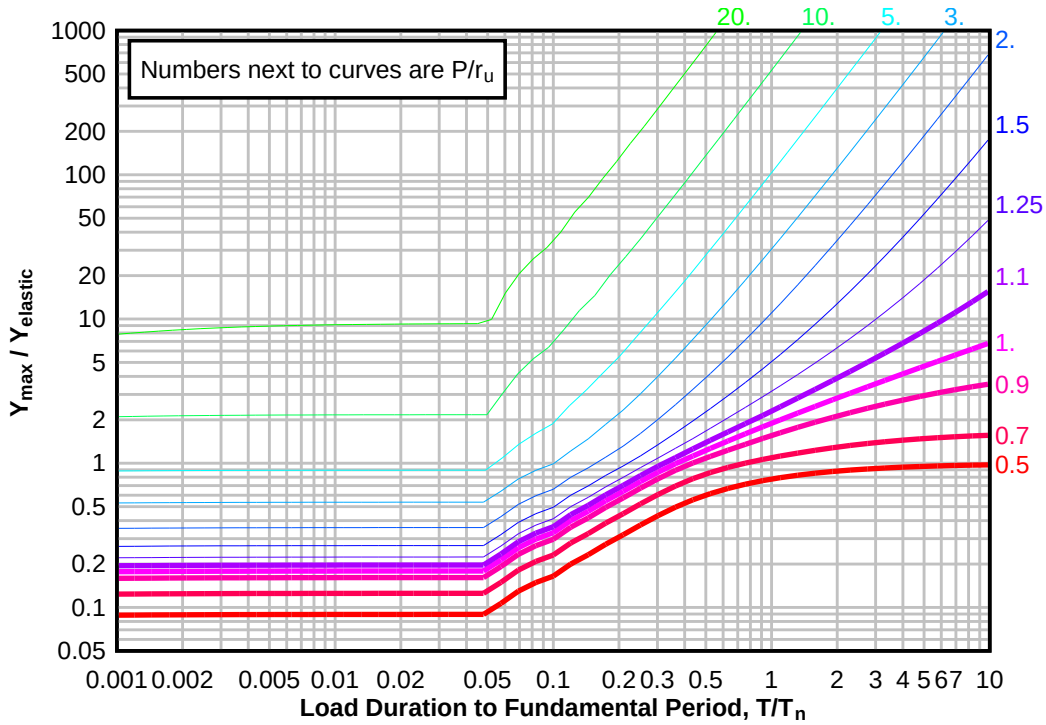


Figure 3-262(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.022, C2 = 1000)

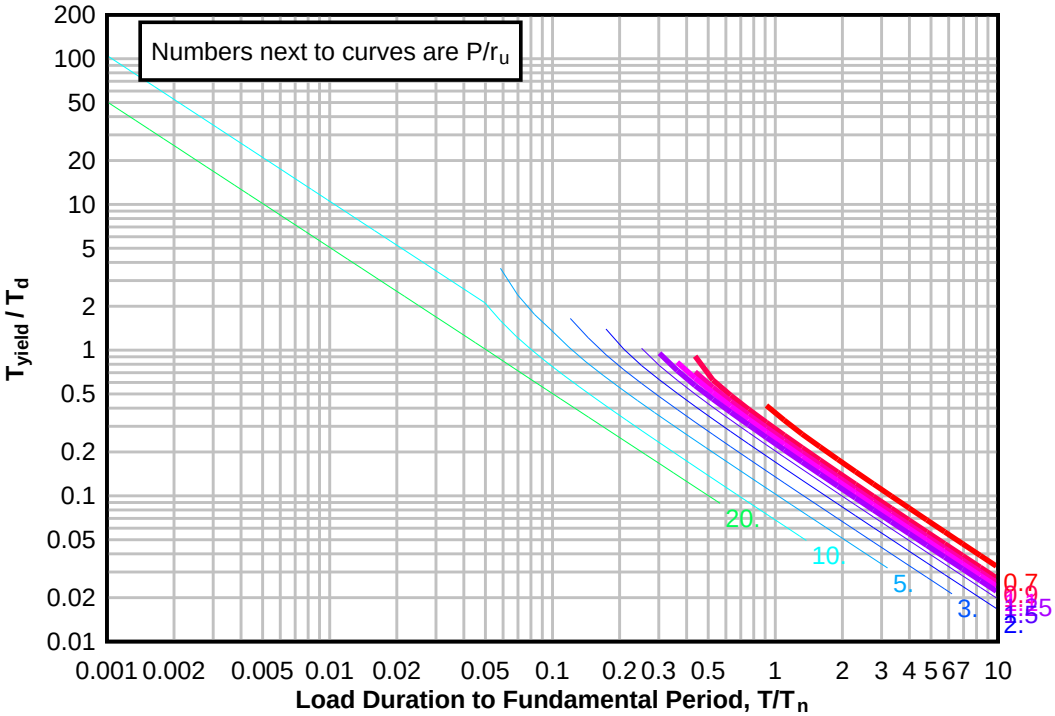


Figure 3-263(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.018, C_2 = 1000)

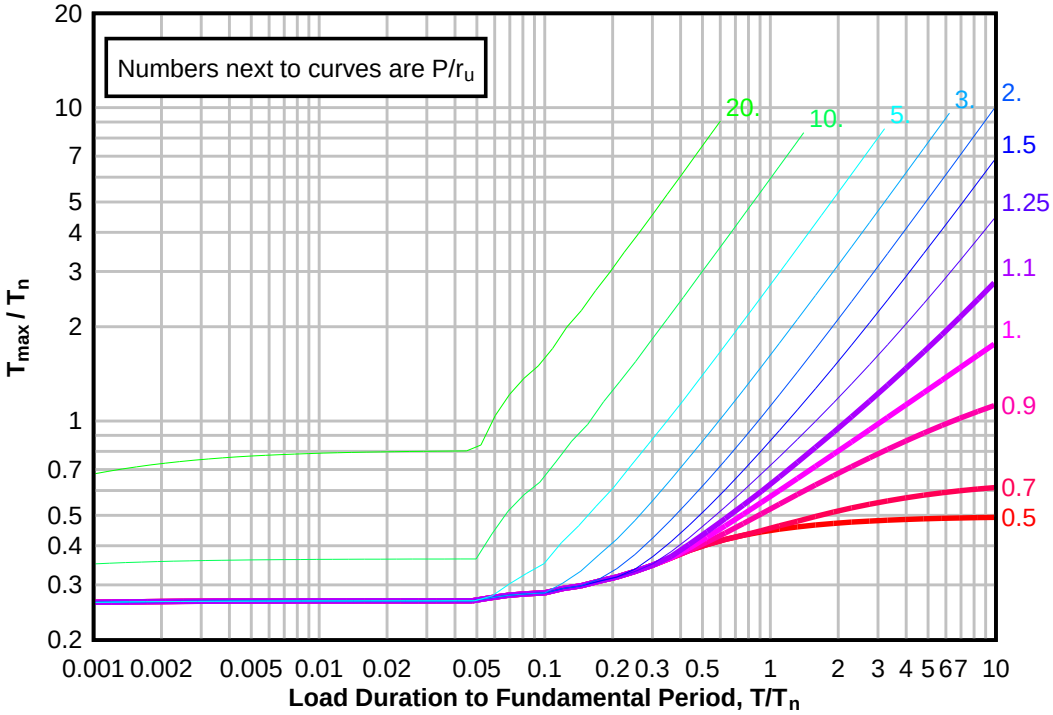


Figure 3-263(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.018, C2 = 1000)

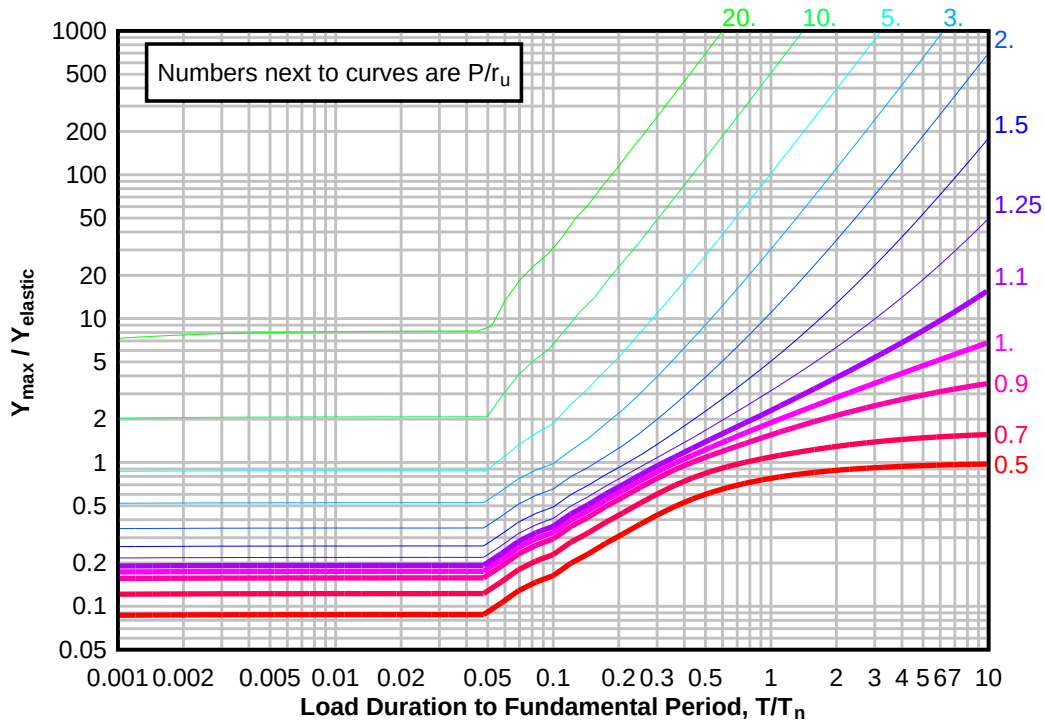


Figure 3-263(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.018, C2 = 1000)

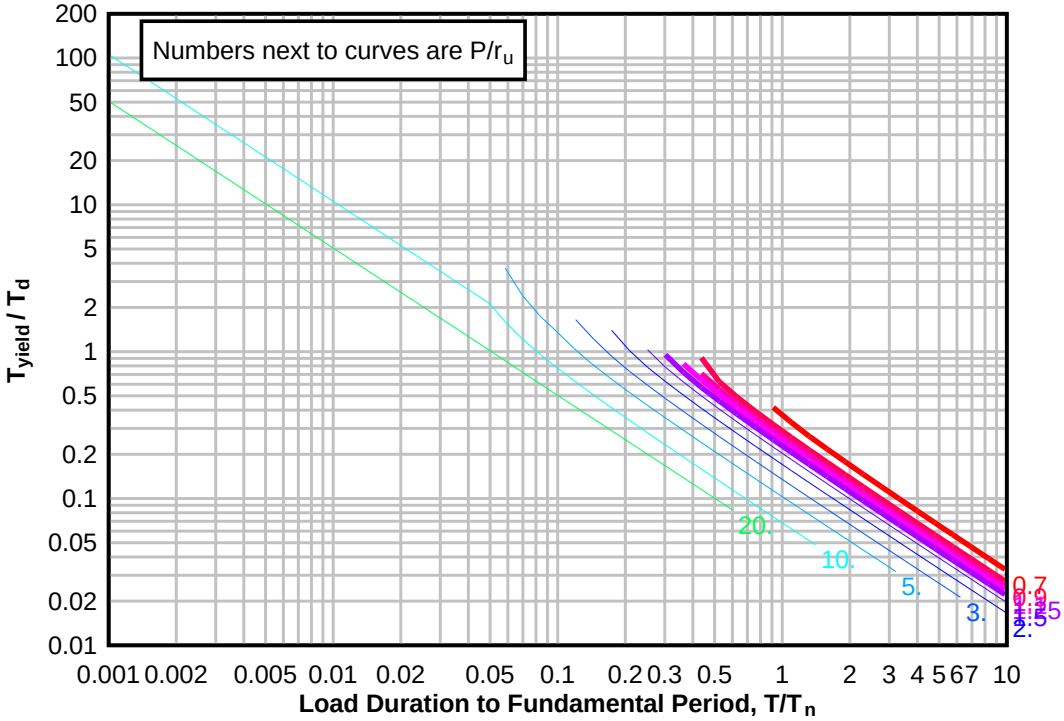


Figure 3-264(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.015, C_2 = 1000)

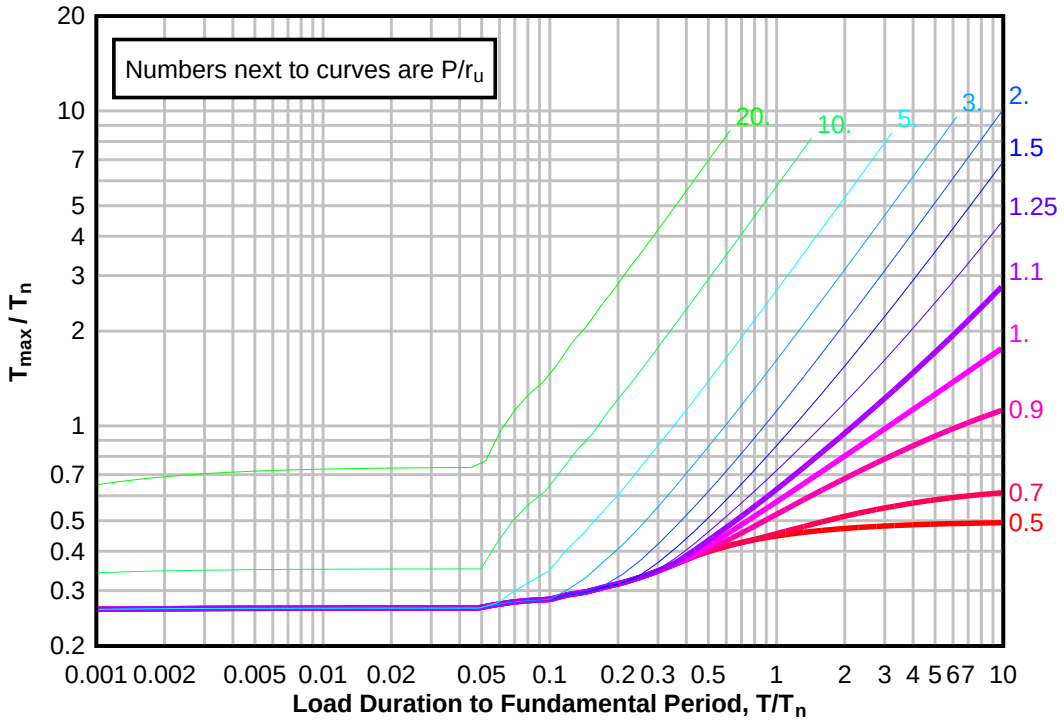


Figure 3-264(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.015, C2 = 1000)

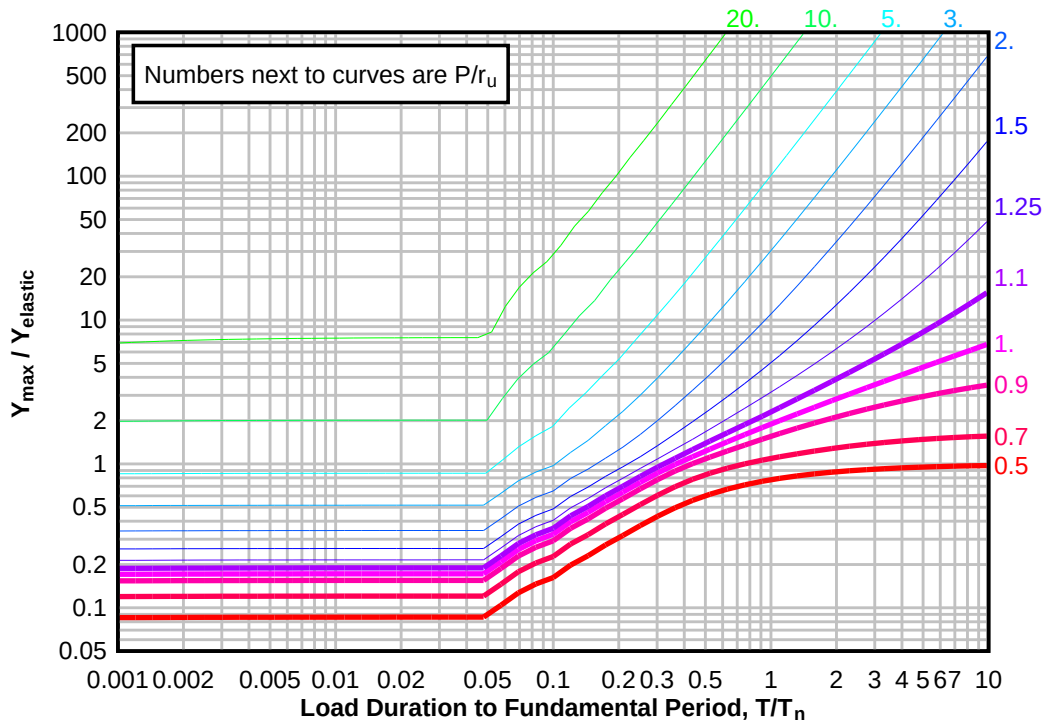


Figure 3-264(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.015, C2 = 1000)

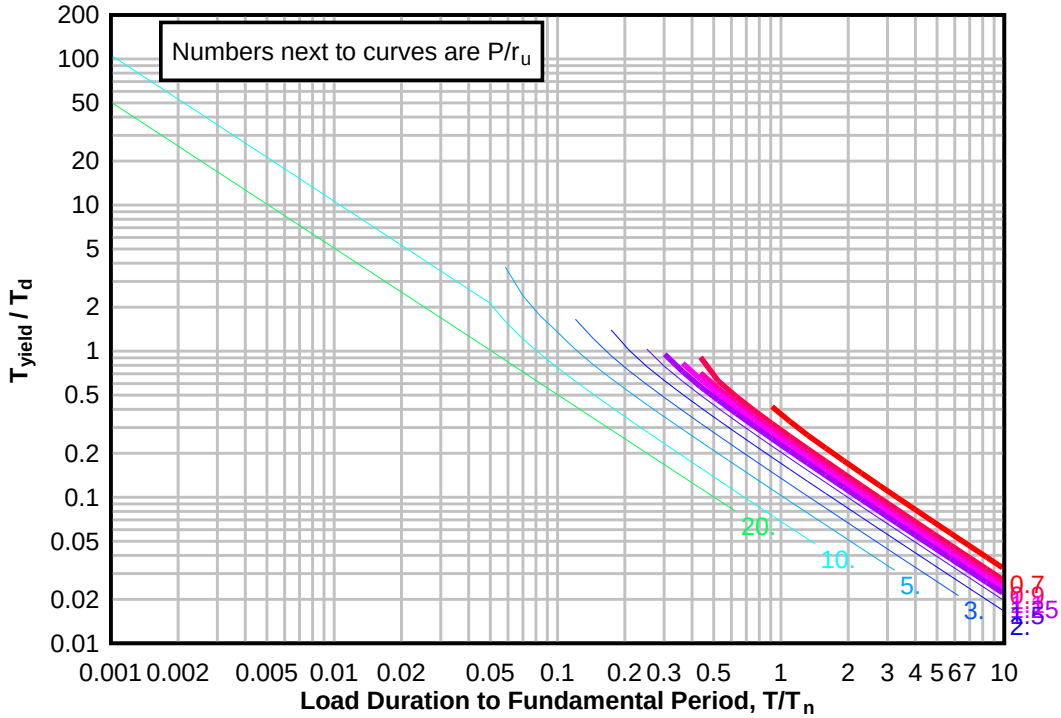


Figure 3-265(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.013, C_2 = 1000)

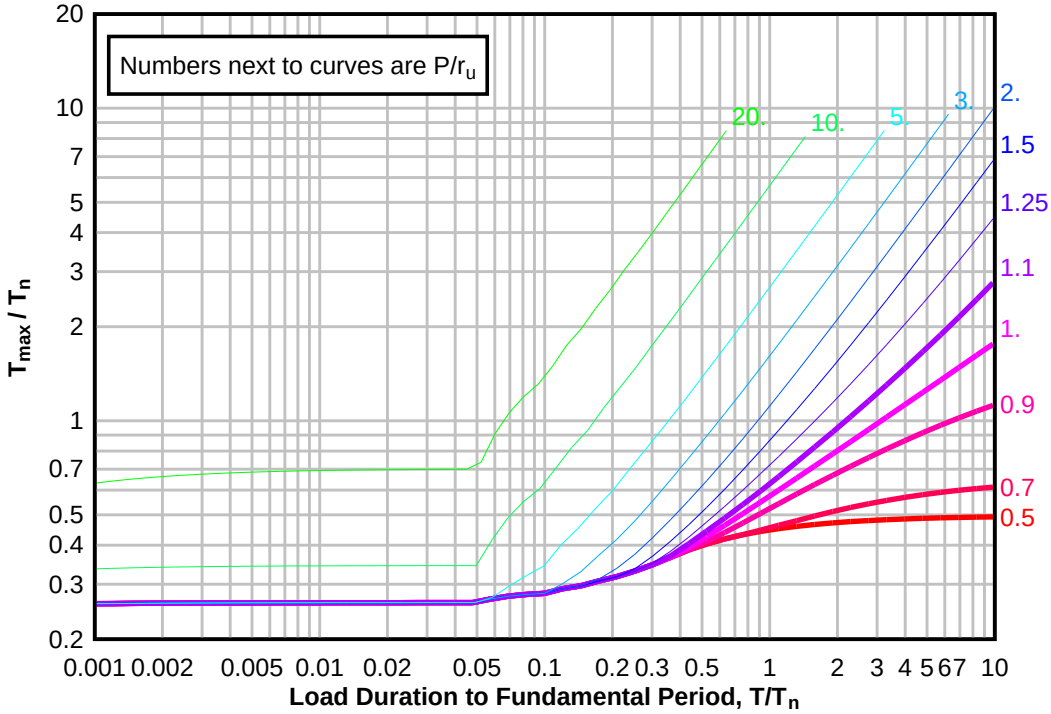


Figure 3-265(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.013, C2 = 1000)

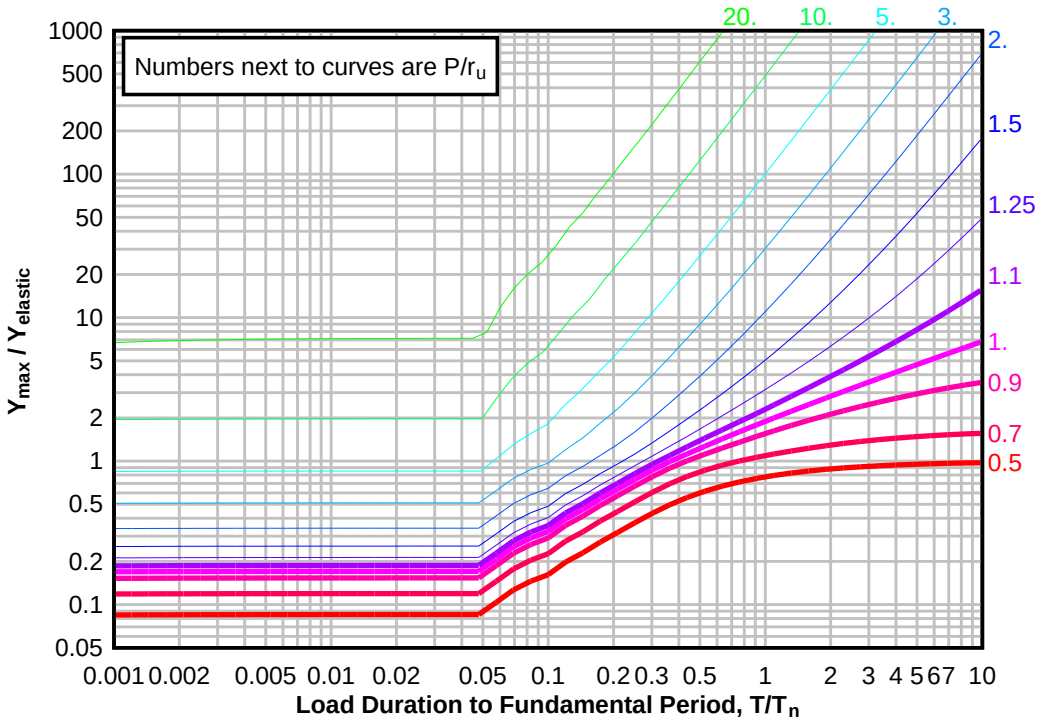


Figure 3-265(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.013, C2 = 1000)

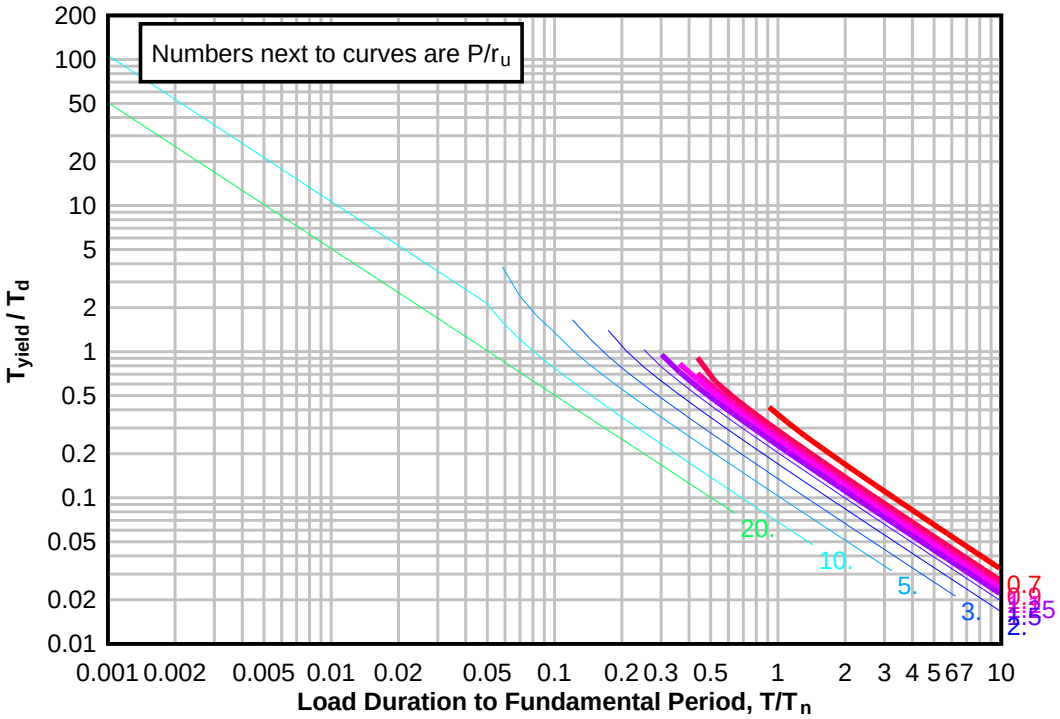


Figure 3-266(a) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C_1 = 0.010, C_2 = 1000)

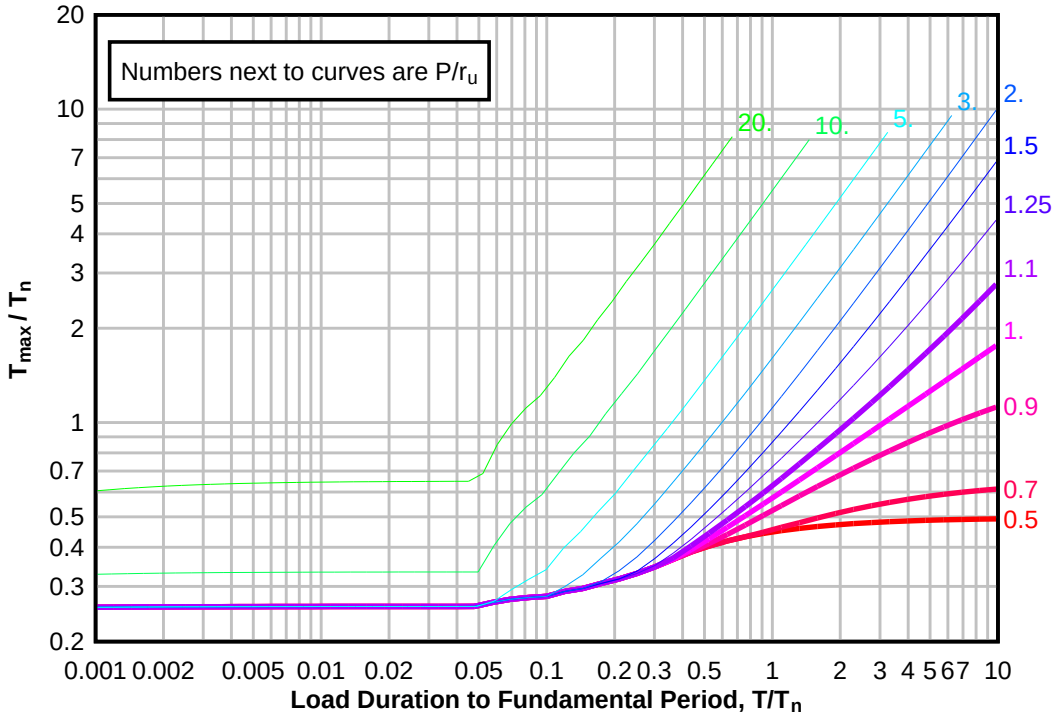


Figure 3-266(b) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.010, C2 = 1000)

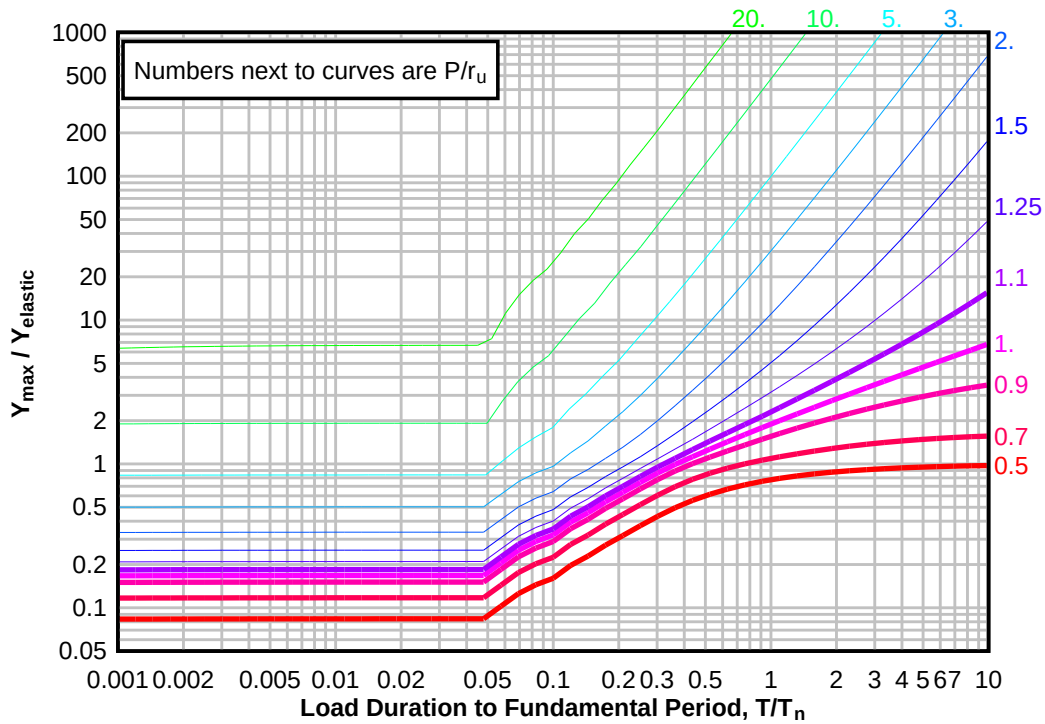


Figure 3-266(c) Maximum Response of Elasto-Plastic, One-Degree-of-Freedom System for Bilinear-Triangular Pulse (C1 = 0.010, C2 = 1000)

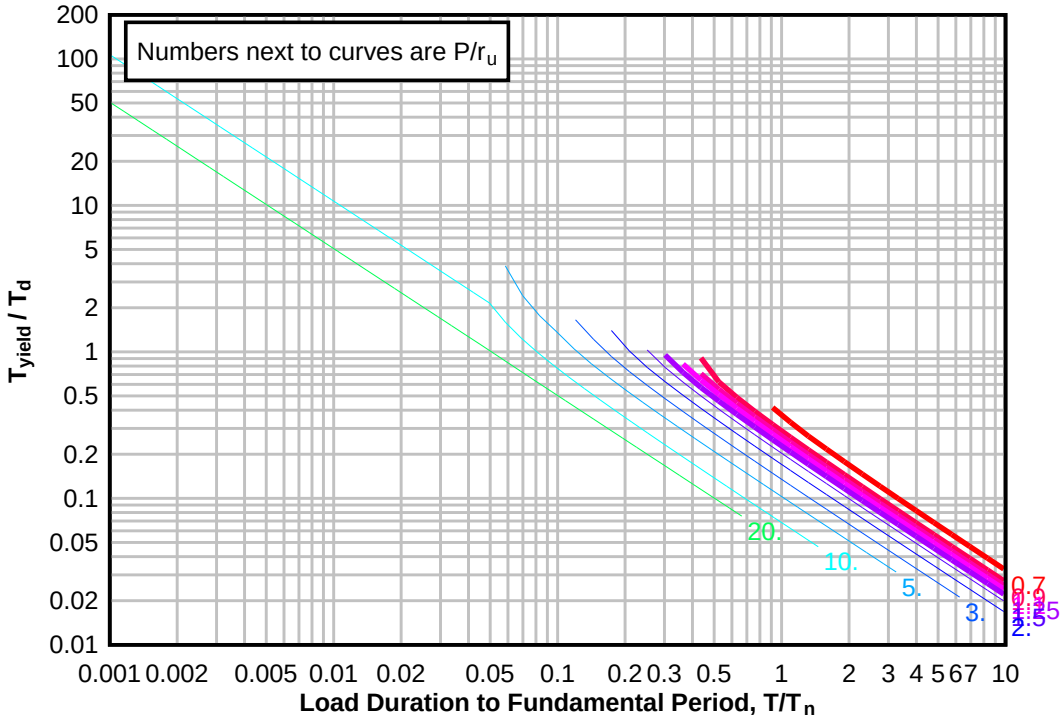


Figure 3-267 Graphical Interpolation

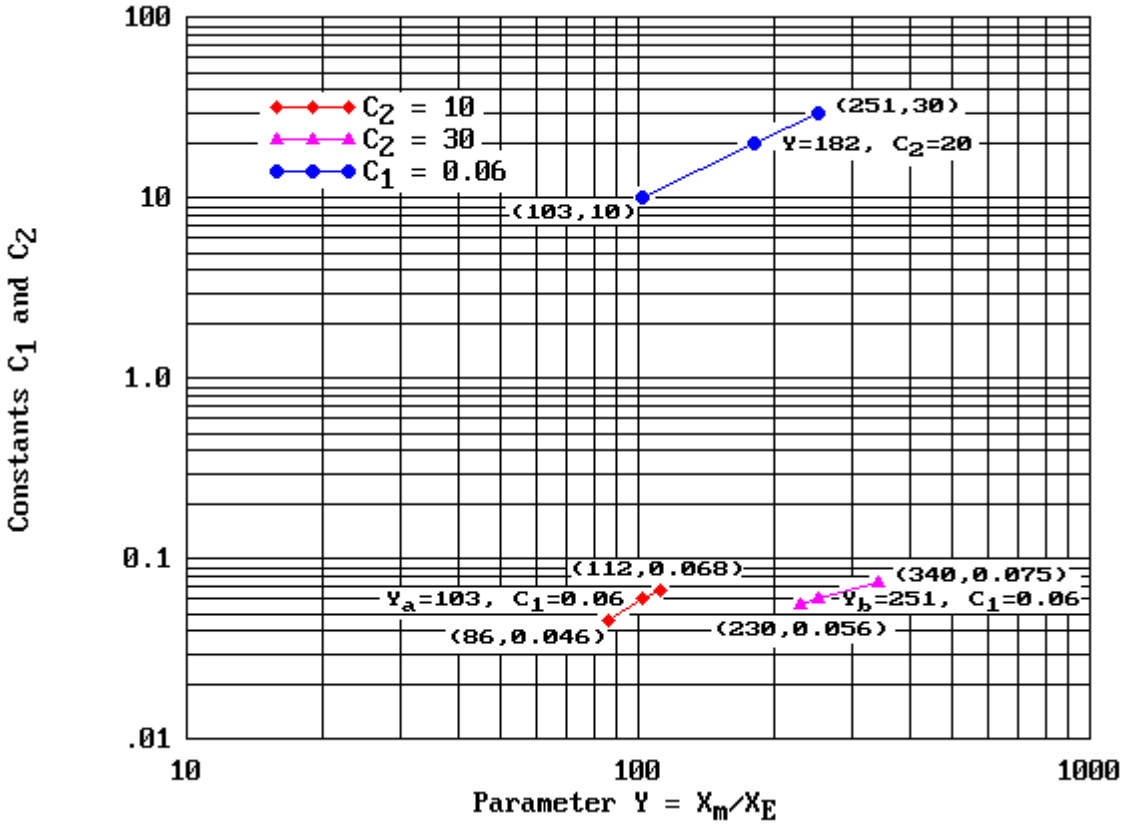


Figure 3-268 Elastic Rebound of Simple Spring-Mass System

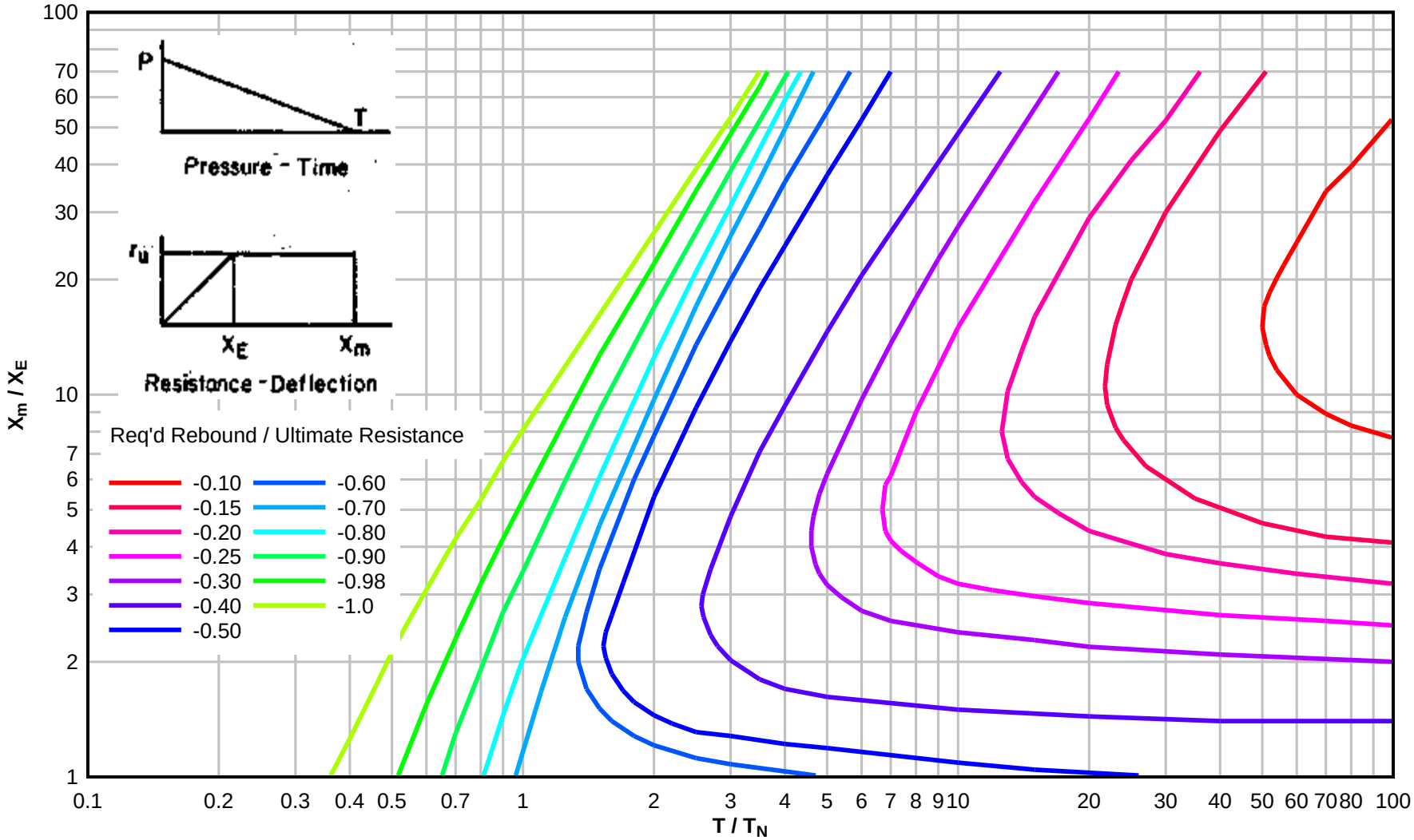


Figure 3-269 Pressure-Time and Resistance Time Curves for Elements Which Respond To Impulse

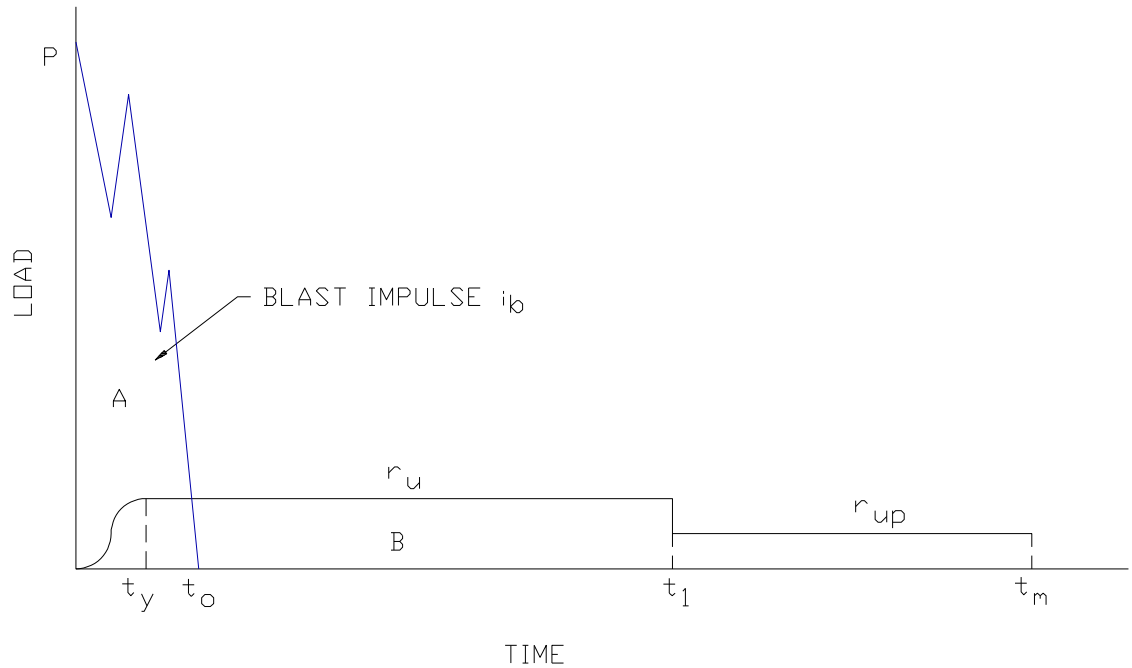


Table 3-14 Details of Computation By Acceleration Impulse Extrapolation Method

n	t	P_n	R_n	$P_n - R_n$	$a_n = (P_n - R_n)/m$	$a_n(\Delta t)^2$	$2X_n$	X_{n-1}	X_{n+1}
0	0	P_0	R_0	$P_0 - R_0$	a_0	$a_0(\Delta t_1)^2$	0	0	X_1
1	Δt_1	P_1	R_1	$P_1 - R_1$	a_1	$a_1(\Delta t_1)^2$	$2X_1$	0	X_2
2	$2(\Delta t_1)$	P_2	R_2	$P_2 - R_2$	a_2	$a_2(\Delta t_1)^2$	$2X_2$	X_1	X_3
.									
.									
j-1	$(j-1)\Delta t_1$	P_{j-1}	R_{j-1}	$P_{j-1} - R_{j-1}$	a_{j-1}	$a_{j-1}(\Delta t_1)^2$	$2X_{j-1}$	X_{j-2}	X_j
j	$j\Delta t_1$	P_j	R_j	$P_j - R_j$	a_j	$a_j(\Delta t_1)^2$	$2X_j$	X_{j-1}	X_{j+1}
j+1	$j(\Delta t_1)+\Delta t_2$	P_{j+1}	R_{j+1}	$P_{j+1} - R_{j+1}$	a_{j+1}	$a_{j+1}(\Delta t_1)^2$	$2X_{j+1}$	X_{j-1}	X_{j+2}

Table 3-15 Figure Numbers Corresponding To Various Combinations of C_1 and C_2

C1 \ C2	1.00	1.70	3.00	5.50	10.0	30.0	100	300	1000
1.000	3-64	3-64	3-64	3-64	3-64	3-64	3-64	3-64	3-64
0.909						3-114	3-141	3-173	3-220
0.866						3-115	3-142	3-174	3-221
0.825						3-116	3-143	3-175	3-222
0.787							3-144	3-176	3-223
0.750				3-85	3-99	3-117	3-145	3-177	3-224
0.715						3-118	3-146	3-178	3-225
0.681	3-64	3-65	3-75			3-119	3-147	3-179	3-226
0.648					3-100	3-120	3-148	3-180	3-227
0.619						3-121	3-149	3-181	3-228
0.590							3-150	3-182	3-229
0.562				3-86	3-101	3-122	3-151	3-183	3-230
0.536								3-184	3-231
0.511						3-123	3-152	3-185	3-232
0.487								3-186	3-233
0.464	3-64	3-66	3-76			3-124	3-153	3-187	3-234
0.422				3-87	3-102		3-154	3-188	3-235
0.383						3-125		3-189	3-236
0.365							3-155	3-190	3-237
0.348								3-191	3-238
0.316	3-64	3-67	3-77	3-88	3-103	3-126	3-156	3-192	3-239
0.287								3-193	3-240
0.274							3-157	3-194	3-241
0.261						3-127	3-158	3-195	3-242
0.237				3-89	3-104		3-159	3-196	3-243
0.215	3-64	3-68	3-78			3-128	3-160	3-197	3-244
0.198								3-198	3-245
0.178				3-90	3-105	3-129	3-161	3-199	3-246
0.162								3-200	3-247
0.147	3-64	3-69	3-79			3-130	3-162	3-201	3-248
0.133				3-91	3-106			3-202	3-249
0.121						3-131	3-163	3-203	3-250
0.110								3-204	3-251
0.100	3-64	3-70	3-80	3-92	3-107	3-132	3-164	3-205	3-252
0.091								3-206	3-253
0.083								3-207	3-254
0.075						3-133	3-165	3-208	3-255
0.068				3-93	3-108			3-209	3-256
0.056	3-64	3-71	3-81			3-134	3-166	3-210	3-257
0.046				3-94	3-109			3-211	3-258
0.042						3-135	3-167	3-212	3-259
0.032	3-64	3-72	3-82	3-95	3-110	3-136	3-168	3-213	3-260
0.026						3-137	3-169	3-214	3-261
0.022				3-96	3-111			3-215	3-262
0.018	3-64	3-73	3-83			3-138	3-170	3-216	3-263
0.015				3-97	3-112			3-217	3-264
0.013						3-139	3-171	3-218	3-265
0.010	3-64	3-74	3-84	3-98	3-113	3-140	3-172	3-219	3-266

Table 3-16 Response Chart Interpolation

<table>
<tr><th>Number</th><th>C_1</th><th>C_2</th><th colspan="3">Desired Parameter</th></tr>
<tr><td rowspan="2">1</td><td>C_{11}</td><td>C_{21}</td><td rowspan="2">Y_1</td><td rowspan="4">Y_a</td><td rowspan="7">Y</td></tr>
<tr><td>C_1</td><td>C_{21}</td></tr>
<tr><td rowspan="2">2</td><td>C_{12}</td><td>C_{22}=C_{21}</td><td rowspan="2">Y_2</td></tr>
<tr><td>C_1</td><td>C_2</td></tr>
<tr><td rowspan="2">3</td><td>C_{13}</td><td>C_{23}</td><td rowspan="2">Y_3</td><td rowspan="3">Y_b</td></tr>
<tr><td>C_1</td><td>C_{23}</td></tr>
<tr><td>4</td><td>C_{14}</td><td>C_{24}=C_{23}</td><td>Y_4</td></tr>
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