:A)

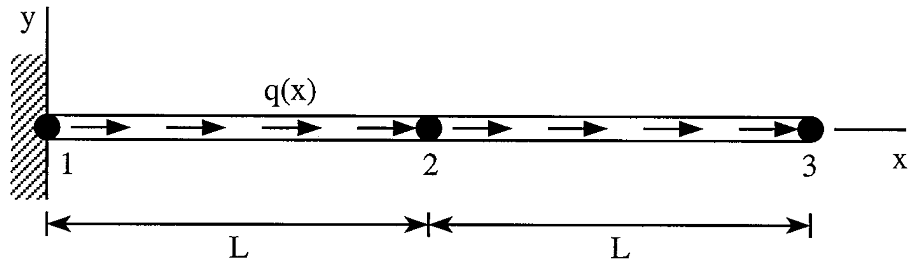
Qualified Examination

Fall 2004

Finite Element Method

(Close book, 100 minutes, 60% to pass)

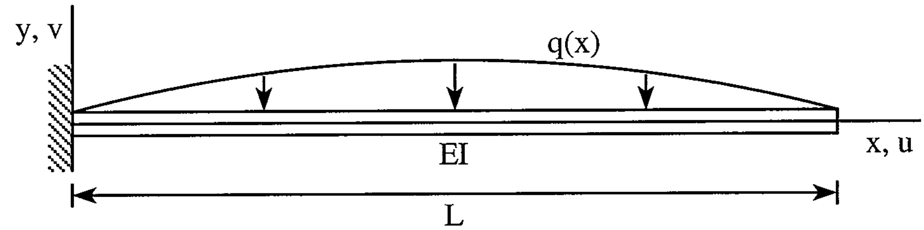
A1. A bar of length 2L is subjected to linearly varying axial load q(x) = c(2L-x), where c is a constant. Let the bar be divided into two elements. (i) Determine the consistent nodal loads at nodes 1, 2 and 3. (ii) Find the axial displacements at all the nodes. (iii) Calculate the stresses in both elements. (15%)



A2. A cantilever beam is subjected to laterally distributed load q(x) (force per unit length) as shown. Let the potential energy Π_p of the beam (weak form) be

$$\Pi_p = \frac{EI}{2}\int_0^L v_{,xx}^2 dx - \int_0^L qv dx$$

where $v_{,xx} = d^2v/dx^2$. (i) What are the essential boundary conditions of the beam? (ii) From the calculus of variations, find the governing differential equation (strong form) and nonessential boundary conditions of the beam. (20%)



A3. To analyze a two-dimensional plane stress structure, there are four types of isoparametric elements may be used, which are 4-node element with full integration, 4-node element with reduced integration, 8-node element with full integration, and 8-node element with reduced integration. Make your comments on the performance of each element and select the most appropriate element you would use for the analysis. (15%)

(B)

(1) Please explain how to write computer software to perform a linear finite element analysis. (50/3)

(2) Please explain the advantages and disadvantages of the high-order element (the element has high-order shape functions). To overcome the drawback of the linear shape function, please illustrate in detail at least one method, such as incompatible mode. (50/3)

(3) Use the 1 by 1 and 2 by 2 Gauss rule to approximate I ($I=\int\int\frac{1+x^2}{y}dxdy$) over the rectangular region shown in Fig.1. (50/3)

Order n	Sampling point	Weight factor
1	0	2
2	$\pm 1/\sqrt{3}$	1

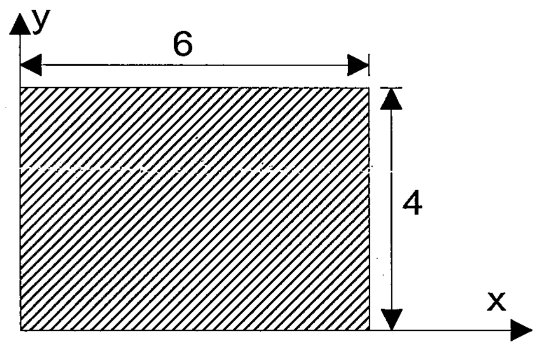


Fig.1

1. Show that the invariants of strain tensor are given by

$$\vartheta_1 = \varepsilon_{11} + \varepsilon_{22} + \varepsilon_{33} = \varepsilon_1 + \varepsilon_2 + \varepsilon_3$$

$$\vartheta_2 = \begin{vmatrix} \varepsilon_{11} & \varepsilon_{12} \\ \varepsilon_{21} & \varepsilon_{22} \end{vmatrix} + \begin{vmatrix} \varepsilon_{22} & \varepsilon_{23} \\ \varepsilon_{32} & \varepsilon_{33} \end{vmatrix} + \begin{vmatrix} \varepsilon_{33} & \varepsilon_{31} \\ \varepsilon_{13} & \varepsilon_{11} \end{vmatrix} = \varepsilon_1\varepsilon_2 + \varepsilon_2\varepsilon_3 + \varepsilon_3\varepsilon_1$$

$$\vartheta_3 = \begin{vmatrix} \varepsilon_{11} & \varepsilon_{12} & \varepsilon_{13} \\ \varepsilon_{21} & \varepsilon_{22} & \varepsilon_{23} \\ \varepsilon_{31} & \varepsilon_{32} & \varepsilon_{33} \end{vmatrix} = \varepsilon_1\varepsilon_2\varepsilon_3$$

where ε_1, ε_2, ε_3 are principal normal strain components.

2. Show that in an isotropic body the principal axes of strain coincide with those of stress.

3. We consider a beam clamped at one end ($x = 0$) and supported at the other end ($x = l$) with a spring of stiffness k and is subjected to a distributed lateral load $p(x)$ per unit span acting in the direction of the z-axis. Show that the functional for the principle of stationary potential energy of this problem is given by

$$\Pi = \frac{1}{2}\int_0^l EI(w'')^2\,dx + \frac{1}{2}k[w(l)]^2 - \int_0^l pw\,dx$$

with subsidiary conditions w(0) = w'(0) = 0, and derive the governing equation and boundary conditions.

4. An elastic solid of unbounded extend has a circular cylindrical cavity with radius a. The cavity contains a gas under pressure p_0. Find the displacement, stress, and strain field in the solid. Assume a condition of plane strain.

(A)

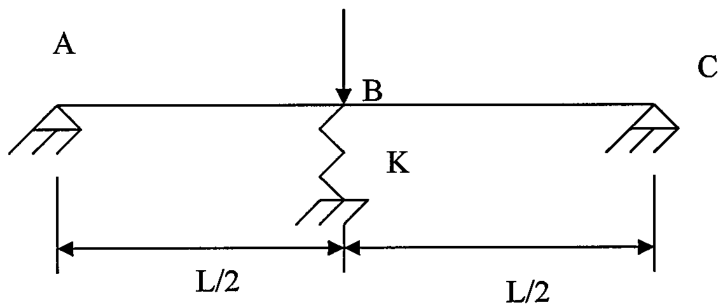
Qualifying Examination (Structural Dynamics)

A1. An undamped system is driven by a harmonic function as shown

$$\ddot{x}+16x=F(t)=\begin{cases}\cos 4t & if\ 0\le t<\pi \\ 0 & elsewhere\end{cases}$$

The initial conditions are $x(0)=0$ and $\dot{x}(0)=1$. Find the response of the system.(25%)

A2. A spring of stiffness K is attached to a uniform beam of mass m/unit length, and bending stiffness EI. Consider the system as a single degree of freedom system with the deflection of point B as the coordinate. Determine the natural frequency.(25%)



(B)

九十三學年度第一學期土木所博士學位候選人資格考試

結構動力學 (Part B)

B1 某一兩層樓縮尺建築物在振動台上以正弦波基底振動進行掃頻，同時量測天花板質心達穩態反應時，相對於基底的位移振幅a（一樓）和b（二樓）。

(a) 當正弦波基底振動的頻率為ω時，兩樓天花板質心相對位移的振幅分別為$a(\omega)$和$b(\omega)$，試分別繪出$a(\omega)$和$b(\omega)$之示意圖（即振幅和頻率之關係圖）。（**10分**）

(b) 當正弦波基底振動的頻率為ω_1時，$b(\omega_1)$達最大值b_1，此時$a(\omega_1)=a_1$；當正弦波基底振動的頻率為ω_2時，$b(\omega_2)$達次大值b_2，此時$a(\omega_2)=a_2$。試以a_1、b_1、a_2和b_2，分別表示二樓相對於一樓的質量比和勁度比，並列出你的假設。（**10分**）

B2 以SRSS法和CQC法進行各振態最大反應之組合時，若兩振態的頻率接近，試問SRSS法所得值會大於或小於CQC法所得值？為什麼？（**10分**）

B3 已知一個多自由度剪力構架(shear frame)的質量和勁度矩陣，可經由振態分析方法，求得各振態頻率和向量。反過來說，若經由系統識別技巧，求出各振態頻率和向量，試問是否可反算質量和勁度矩陣的每一個元素？為什麼？（**10分**）

B4 一個龐大的多自由度建築物以多振態設計震譜疊加法進行動力分析時，國內規範只要求所考慮之振態數目應使各方向之有效振態質量和均已超過建築物總質量的90%即可。換句話說，那些可能達建築物總質量10%的高振態反應微乎其微，試詳述其原因或補救方法。（**10分**）

Engineering Mathematics

QUALIFYING EXAM

October 29, 2004

1. (20%) The steady-sate temperature distribution in a finite cylinder of radius 1 and length a is governed by the problem

$$\frac{\partial^2 u}{\partial r^2} + \frac{1}{r}\frac{\partial u}{\partial r} + \frac{\partial^2 u}{\partial z^2} = 0, \quad r < 1,\ 0 < z < a,$$
$$u(r,0) = f(r),\ u(r,a) = 0,\ u(1,z) = 0.$$

Find a series expression for $u(r,z)$.

2. (20%) Solve the Euler-Lagrange equation appropriate for the functional

$$I(y) = \int_{-a}^{a} y\sqrt{1+(y')^2}\,dx,$$

where $y(x)$ satisfies the boundary conditions $y(-a) = A$ and $y(a) = A$.

3. (20%) Explain (i) self-adjoint, (ii) Legendre polynomial, (iii) elliptical type of PDE, (iv) spherical harmonics.

4. Consider the Sturn-Liouville problem

$$x^2\frac{d^2y}{dx^2} + x\frac{dy}{dx} + \lambda y = 0, \quad y(0) = 0,\ y(b) = 0,\ b > 1.$$

Derive the characteristic numbers λ (7%) and their corresponding characteristic functions $\varphi_n(x)$ (8%). If $f(x)$ is piecewise differentiable in the interval $(1,b)$, and if

$$f(x) = \sum_{n=1}^{\infty} A_n\varphi_n(x),$$

find the expansion coefficient A_n (5%).

5. (10%) Prove that any function can always be regarded as a sum of an even function and an odd function.

6. (10%) Show that

$$\int_0^\infty \frac{dx}{(x^2+a^2)^2} = \frac{\pi}{4a^3}, \quad a > 0.$$

九十三年度第二學期博士候選人資格考**土壤力學**試題

一・翻譯及解釋下列名詞: (25%)

(1) constrained modulus (2) consolidation (3) overconsolidation ratio
(4) consistency (5) hydraulic gradient

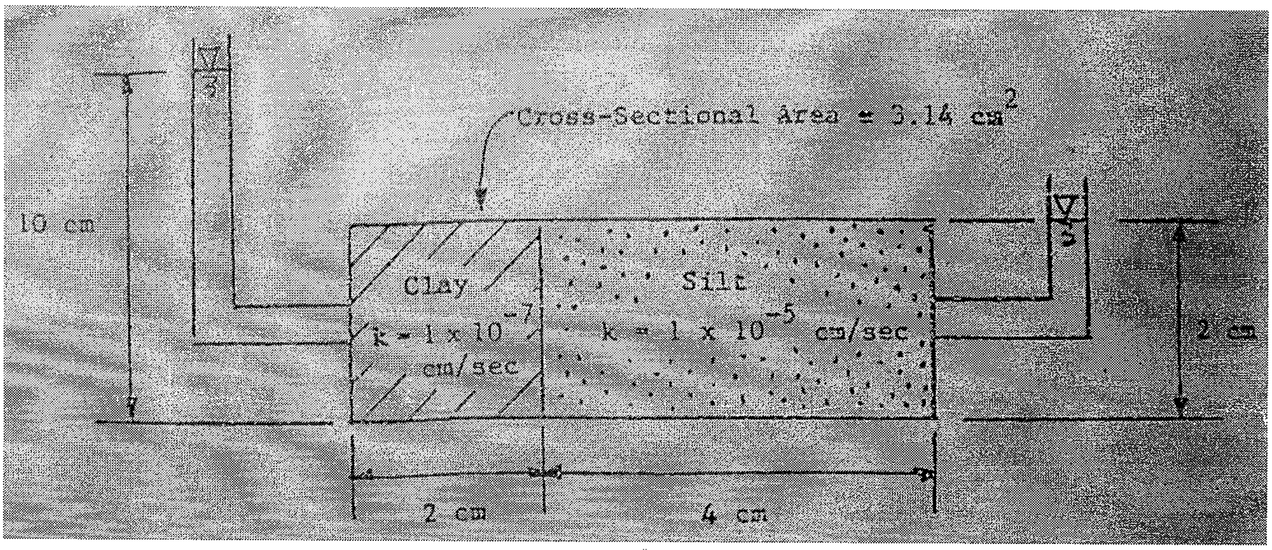
二・Triaxial compression tests were performed on a dry sand, $\phi' = 35$ degrees. Prior to shear each specimen was subjected to an isotropic confining (cell) pressure of 200 kPa. Specimens were then sheared with the following four loading path. (28%)

1. Compression - axial stress increased to failure (lateral stress constant).
2. Compression – lateral stress decreased to failure (axial stress constant).
3. Extension - axial stress decreased to failure (lateral stress constant).
4. Extension - lateral stress increased to failure (axial stress constant).

For each of these loading paths complete the following:

a. Construct the Mohr's circle for stresses at failure and locate the pole point (origin of planes)
b. Determine the major and minor principal stresses at failure and indicate which of these is the axial stress and which is the lateral stress.
c. Determine and illustrate by means of a sketch the orientation of the failure planes.

三・Plot the rate of flow, discharge velocity, total head and pore water pressure as a function of position along the path of flow, and draw the flow net in the soil for the following cases: (Note: use the base of the sample as the datum.) (27%)



四・試寫出 Terzaghi 單向壓密理論之基本假設(至少五個)，並說明如何導出壓密之基本方程式 $\frac{\partial \cdot u}{\partial \cdot t} = c_v \frac{\partial^2 u}{\partial \cdot z^2}$ 。 (20%)

姓名:__________

學號:__________

93 學年博士課程資格考試岩石力學試題(2004.10)

(1.Close Book　　　　2.試題與試卷一起交回)

1. 進行一組岩石三軸壓縮試驗，得到試體破壞時各試體之應力狀態為：

Test No.	σ_3(MPa)	σ_1(MPa)
1	1.0	9.2
2	5.0	28.0
3	10.0	49.0
4	15.0	74.0

(a)請繪此組岩石試體的破壞應力 Mohr 圓包絡線。

(b)若此岩石的單軸壓縮強度為 5 MPa，請問 Hoek and Brown 破壞準則中 m 及 s 之值為何？

$$\sigma_1 = \sigma_3 + \sqrt{m\sigma_c\sigma_3 + s\sigma_c^{\ 2}}$$ (25%)

2. 請說明如何求得岩石材料的完整應力－應變曲線(Complete Stress-Strain Curve)？此曲線在岩盤工程上有何用處？(20%)

3. 請繪圖說明圍壓(Confining Pressure)及溫度對岩石材料的應力－應變曲線的影響？還有何種因素會影響岩石的應力－應變曲線(10%)

4. 何謂現地應力，如何求之？(10%)

5. 請說明火成岩、沈積岩、變質岩之成因？再說明各種岩石分佈於我國的位置以及其與我國的地質構造間的關係。(20%)

6. 解釋名詞(15%)

①關鍵岩塊(Key Block)

②走向與傾斜(Strike and Dip)

③節理與斷層(Joint and Fault)

國立成功大學土木工程學系博士班資格考試工程地質試題

October 29, 2004

Note: 每題各為 **10** 分

1. 最近台灣及日本地震頻傳，地震產生之原因仍有待探討。氣象局則以「這是正常的能量釋放現象」說明之，這也可能為原因之一，若果此因為真，試以「地殼板塊學說」解釋最近地震發生之現象。可以繪圖輔助解釋之。

2. 一般而言，台灣可分成那三個地質分區，試以繪圖說明並指出其相對產生年代之早晚。

3. 至少指出台灣三個地層，說明其概略分佈之地理位置並分別說明各地層之主要工程特性。

4. 依據美國原子能委員會(U.S. Atomic Energy Commission)所訂之標準，定義「活動斷層」。依據此標準，台灣之活動斷層可分成幾類。指出至少三條台灣之活動斷層。

5. 在地質圖判別地層與地形之關係時，有所謂「V 字法則」可依循，是指何物，試說明之。

6. 大地主應力方向不同將造成不同之斷層類別，說明二者之關係。

7. 台灣各河川自上流至下流均包含三個發育階段，橋樑工程在此三階段發育之地區進行時，就地質條件而言，應分別注意那些事項。

8. 台北盆地與高雄都會區之環境地質歷史有明顯不同，試說明其最主要差異。大地工程在此二地區進行時，必須注意那些事項，試分別說明之。

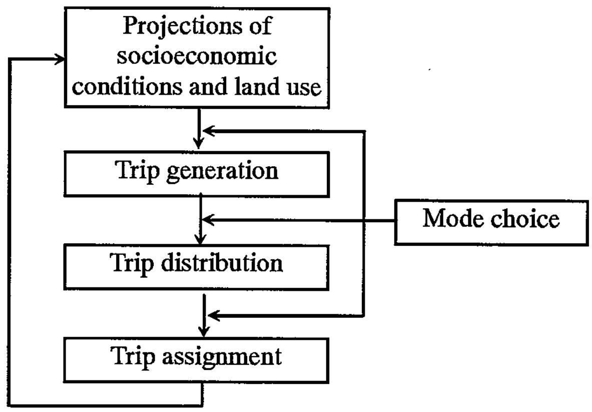
9. 近年來，台灣大部分水庫淤積嚴重，試分別就自然因素與人為因素，說明其造成之主要原因。

10. 一般隧道工程之地質調查應包含那些事項。

成功大學土木工程系九十三學年博士班資格考試
交通工程試題

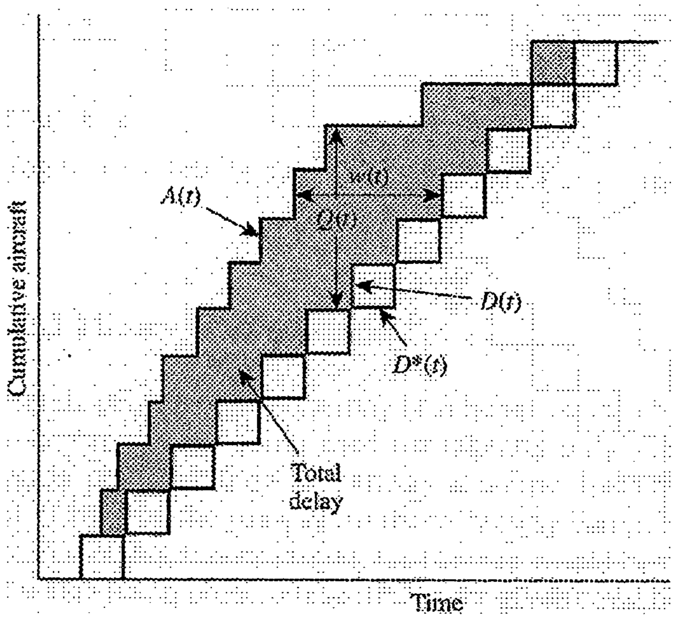
一、 請解釋「macroscopic traffic flow model」與「microscopic traffic flow model」(10%)。 並說明這兩者間的關係 (15%)

二、 請解釋下圖之涵義(25%)



三、 請說明 Transportation planning 的目的與概要內容。(25%)

四、 請說明下圖各參數之意義。(25%)



National Cheng Kung University, Department of Civil Engineering

Paving Materials

Qualification Exam for Ph.D. Students

Open Books and Notes (100 minutes)

Fall 2004

1. Assumed that you are the asphalt manager in charging of selling asphalt products to foreign countries. You receive the following letter:

Dear Sir:

Subject: Absolute Viscosity of Paving Asphalt AR-8000.

This is refers to the test result of Absolute Viscosity @ 60℃ of Paving Asphalt AR-8000. We have noticed that your test result for absolute viscosity from 1st to 5th delivery increases and also observed the 6th delivery which arrived last September 11, 2004. Your mill certificate showed that absolute viscosity resulted to 8910 poise which is almost in the maximum value of 9000 poise as per specification.

This matter alarmed us so we would like to request your office to explain how absolute viscosity increases from 7902 of 5th delivery to 8910 poise 6th delivery.

Project Manager,

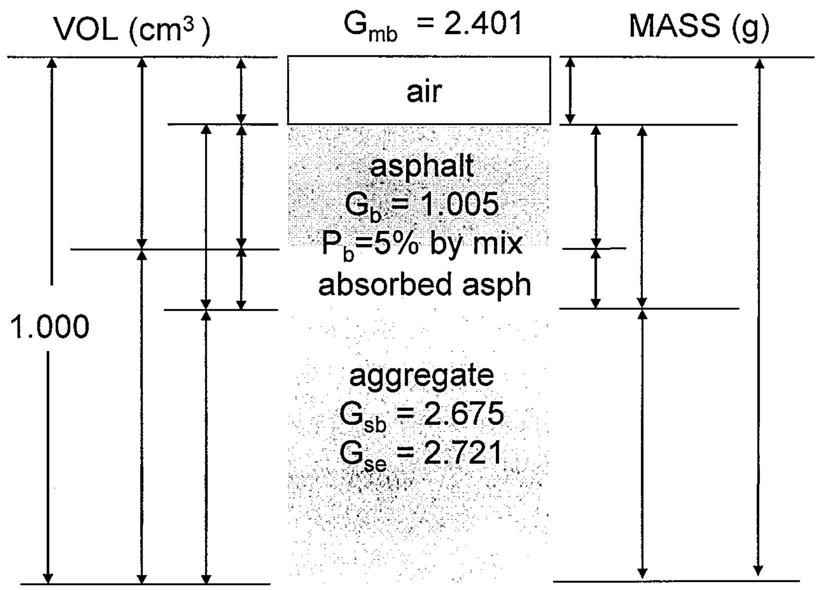
Ejaz Sharif
Pala Compact Road Project

What will be your response? Please clarify your points with reasonable explanations. (25%)

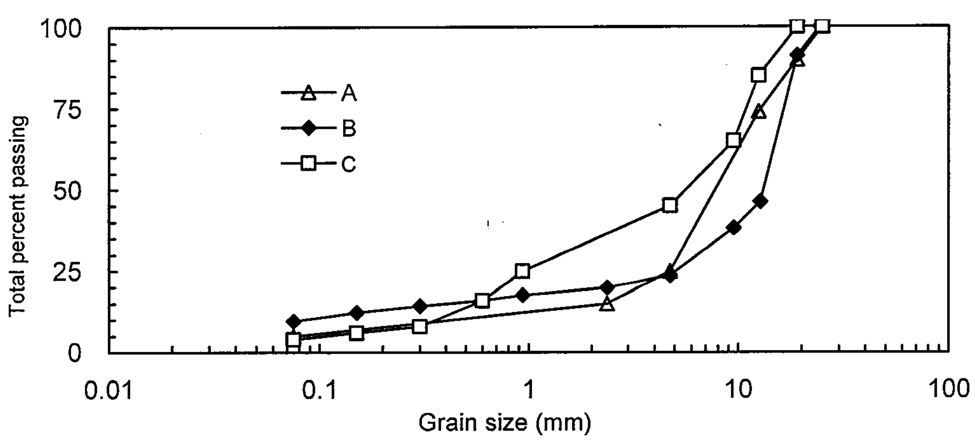
2. Although the use of reclaimed asphalt pavements (RAP) can lead to economical and environmental benefits, the assurance of proper RAP handling and usage in HMA is needed to ensure adequate pavement performance. Currently, the construction specification calls for the maximum of 40% RAP to be used for paving projects. High percentages of RAP are not used in normal practices; however, some construction projects in Taiwan have been observed with unusually high RAP contents in HMA mixtures. Concerns have been raised regarding the effect of a high RAP content on pavement performance. It is imperative that guideline be

established to determine the RAP content in a HMA mixture after a pavement project is finished. You are asked to identify and/or develop laboratory tests to detect and quantify the amount of RAP in a given mixture. (25%)

3. A compacted specimen of hot-mix asphalt mixtures have been measured at 25°C. The component diagram shown below indicates five properties, i.e., four specific gravities and the asphalt content. As indicated on the component diagram, you are asked to find (1) the volumetric properties, (2) mass quantities, (3) void in mineral aggregate, (4) void filled with asphalt and (5) maximum theoretical density. Please show all your calculations. (25%)



4. Consider various gradation curve shown below. Please identify the curve that best describe a (1) dense-graded asphalt mixture, (2) stone mastic asphalt, and (3) porous asphalt. Also please give your explanations. (25%)



Pavement Engineering

(PhD Qualify Exam.)

1. Although pavement design has gradually evolved from art to science, empiricism still plays an important role even up to the present day. Describe why does art relate to the pavement design? (20%)

2. Briefly describe the evolution of the flexible pavement design methods. (20%)

3. What is the difference between traditional pavement design and a pavement design strategy? (15%)

4. What is the difference in the way flexible and rigid pavements carry load? (15%)

5. List the essential requirements of the pavement management. (15%)

6. Describe the distresses in the HMA pavements. (15%)

本題組之主題為旅行推銷員問題(Traveling Salesman Problem, 簡稱 TSP)。以下每小題 20 分。

(a) 試寫出 TSP 的定義。

(b) [Dantzig, Fulkerson & Johnson, 1954] TSP 可以用下列整數規畫模式表示之。其中 x_{ij} 為雙元整數變數，若節線(i,j)為解的一部份其值為 1，否則為 0。參數 c_{ij} 為節線(i,j)之長度。V 為所有節點所成的集合。S 為一些節點所成的集合。

$$\text{Minimize} \quad \sum_{i\in V}\sum_{j\in V} c_{ij}x_{ij} \qquad (1)$$

Subject to

$$\sum_{j\in V} x_{ij} = 1,\ i\in V$$
$$\sum_{i\in V} x_{ij} = 1,\ j\in V \qquad (2)$$

$$\sum_{i\in S}\sum_{j\in S} x_{ij} \le |S|-1, \quad \text{for all} \quad S\subset V, S\ne\phi, S\ne V \qquad (3)$$

$$x_{ij}\in\{0,1\}, \quad \text{for all} \quad i,j\in V$$

試分別說明式(1)、(2)、(3)的意義。其中式(2)的兩條限制式一併說明即可。

(c) 若有一個 100 個節點的 TSP，對其建立(b)題之數學模式，並以分枝定限法(Branch and bound method)求解。求解時將遭遇何種困難？試具體說明困難所在及其原因。

(d) 以(c)題之數學模式，若將式(3)去除，將對求解難易程度有何影響，原因何在？對求解所得之結果又有何影響，原因何在？

(e) 根據(d)題之方法，建議一個求解 TSP 近似最佳解的方法。

工程時程控制 **Qualification Exam**

1. Consider the following project in Table 1

Table 1

Activity	Duration	Predecessors	Masons	Helpers
A	1	None	2	1
B	4	A	2	1
C	2	A	2	1
D	1	B	1	0
E	4	B	3	0
F	3	C	3	0
G	4	C	1	2
H	2	C	1	1
J	2	D	2	2
K	6	J	2	1
L	2	F, G, H	3	2
M	1	K, L	2	1

1.1. Develop an unrestrained schedule. (10%)

1.2. Develop resource histograms for mason and helpers, respectively. (10%)

1.3. Level the project, using 4 masons and 2 helpers. (20%)

2. Your bonding company has asked for the status of a telecommunications revitalization project (In Table 2). You decided to calculate Schedule Variance (SV), Schedule performance Index (SPI), Cost Variance (CV), and Cost performance index (CPI) as performance indicators. Your cost accounting system section and project manager have provided you with the following information:

2.1. Find the BCWS and BCWP of each activity (fill in the table) (10%)

2.2. Calculate the SV, CV, SPI, and CPI of the project (10%) and determine the performance of the project in terms of schedule and budget. (10%4)

2.3. What possible action can you take to speed up the project without increasing the project cost? (10%)

Table 2

Activity #	Description	Total cost forecast	Scheduled percentage complete	Percentage complete	Actual cost to date	BCWS	BCWP
1	Building permits*	2000	100	100	1253.75		
2	Temp. networks*	25000	100	100	26497.83		
3	Order cable trays	8000	100	100	7907.27		
4	Order routers, cabling	10000	100	100	9017.32		
5	Remove ceilings*	18000	100	100	11427.49		
6	Install cable trays*	28000	100	100	19743.19		
7	New servers*	20000	100	70	11271.25		
8	Cable TV	10000	100	10	793.21		
9	Backbone and routers	20000	100	5	327.19		
10	LANs	17500	20	0			
11	Connect and test*	15000	0	0			
12	New Ceilings*	20000	0	0			
		193500			88238.5		

* Asterisks indicate the critical path for this project

3. 請敘述時程規範有何功用，一標準的時程規範應包含哪些內容。(20 分)

工程成本與財務　博士資格考　93 年 10 月

一、 估價(estimating)是部份藝術、部分科學的過程，請敘述一般估價步驟。又假設估價完成後去投標某一捷運施工案，其成本組成在直接成本、工地間接成本、公司管理費下，大致有哪些成本類別？(30 分)

二、 請自行用六筆交易或會計事項，最好涵蓋資產、負債、業主權益、收入及費用類科目，做分錄於日記簿，過帳至分類帳或 T 字帳，然後結帳，做損益表，及資產負債表。(40 分)

三、 何謂現金流量表？如何建立現金流量表？(30 分)

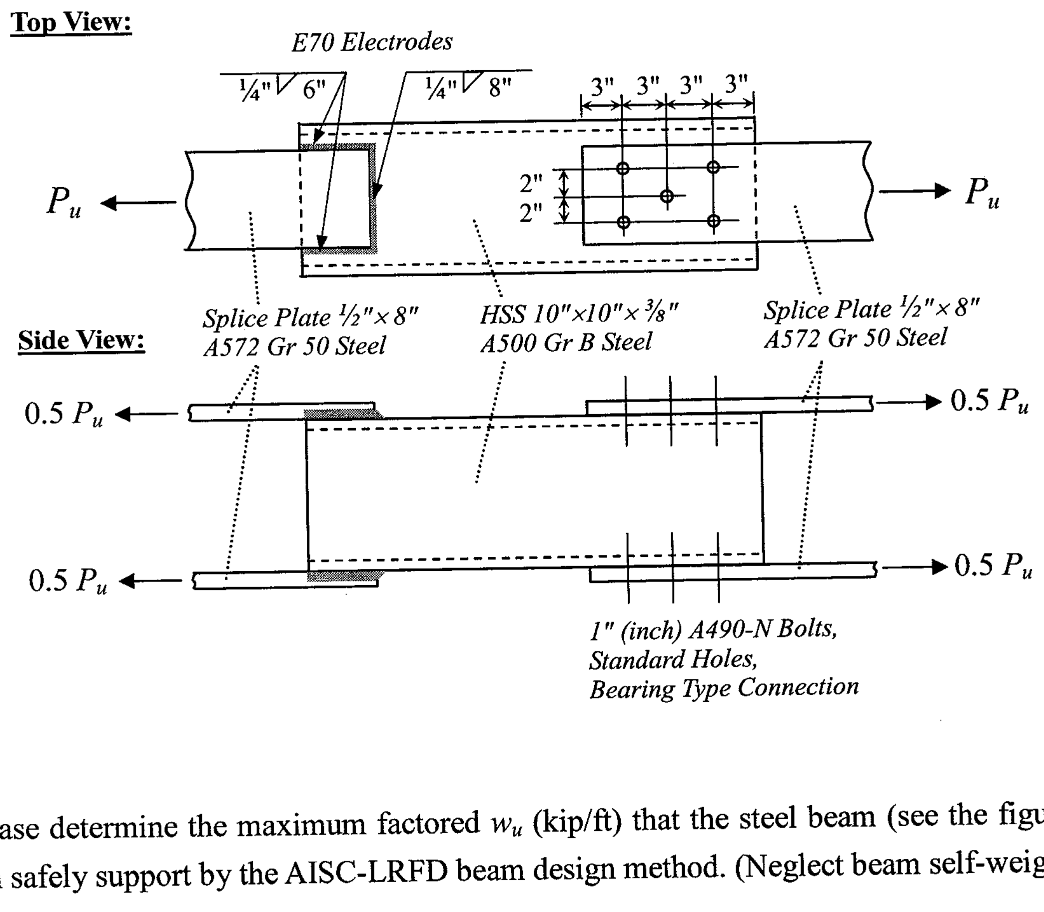
Date: Oct. 29, 2004

PhD Qualifying Exam for "Steel Structures" or "Steel Material & Structures"

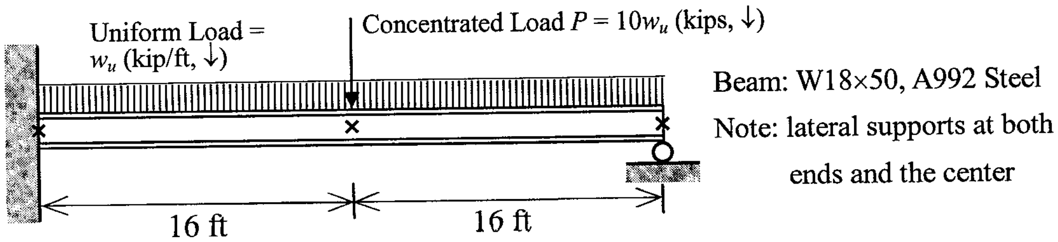
Note: Please solve the following problems in US units (i.e. inch ("), foot ('), kip, lb, ksi, psi ....)

1. Please give detailed explanations for the following questions:
   a.) In the AISC-LRFD Specification, why is the yield condition of steel for shear stress (τ_y) usually taken as 0.6 times of the tensile yield stress (F_y), i.e. $\tau_y = 0.6\ F_y$?
   b.) What is "shear lag" effect? How does it affect the bolted and welded members? How can we reduce this effect?
   c.) What is Charpy V-notch (CVN) test for in steel structures?

2. Please estimate the maximum factored load P_u of the following tension member by the AISC-LRFD method. (You have to check ***all*** the limit states of ***all*** the components in this tension member)



3. Please determine the maximum factored w_u (kip/ft) that the steel beam (see the figure below) can safely support by the AISC-LRFD beam design method. (Neglect beam self-weight)



混凝土材料與結構

(Time: 100 minutes)

1. (a) Define the "initial setting time" and " final setting time" as measured by the penetration resistance method (ASTM C 403).
   (b) What is their significance in the concrete construction practice?
   (c) What are the principal factors controlling the setting time of concrete?
   (20%)

2. Explain
   (a) Plastic shrinkage
   (b) Pozzolanic reaction
   (c) SSD
   (20%)

3. Calculate ϕM_n for singly reinforced rectangular beams having the following properties: b=10 in , d=20 in, Bar= 3 No. 8, $f_c' = 3000psi$, $f_y = 60000psi$.
(20%)

4. Give three reasons why compression reinforcement is used in beams. (20%)

5. Explain how to construct an interaction diagram for a concrete column. (20%)

Table 2-1. Applicable ASTM Specifications for Various Structural Shapes

Steel Type	ASTM Designation		F_y Min. Yield Stress (ksi)	F_u Tensile Stress[a] (ksi)	W	M	S	HP	C	MC	L	HSS Rect.	HSS Round	Steel Pipe
Carbon	A36		36	58–80[b]										
	A53 Gr. B		35	60										
	A500	Gr. B	42	58										
			46	58										
		Gr. C	46	62										
			50	62										
	A501		36	58										
	A529[c]	Gr. 50	50	65–100										
		Gr. 55	55	70–100										
High-Strength Low-Alloy	A572	Gr. 42	42	60										
		Gr. 50	50	65[d]										
		Gr. 55	55	70										
		Gr. 60[e]	60	75										
		Gr. 65[e]	65	80										
	A618[f]	Gr. I & II	50[g]	70[g]										
		Gr. III	50	65										
	A913	50	50[h]	60[h]										
		60	60	75										
		65	65	80										
		70	70	90										
	A992		50–65[i]	65[i]										
Corrosion Resistant High-Strength Low-Alloy	A242		42[j]	63[j]										
			46[k]	67[k]										
			50[l]	70[l]										
	A588		50	70										
	A847[f]		50	70										

■ = Preferred material specification.

▒ = Other applicable material specification, the availability of which should be confirmed prior to specification.

□ = Material specification does not apply.

[a] Minimum unless a range is shown.
[b] For shapes over 426 lb/ft, only the minimum of 58 ksi applies.
[c] Groups 1 and 2 shapes only. To improve weldability a maximum carbon equivalent can be specified (per ASTM Supplementary Requirement S78). If desired, maximum tensile stress of 90 ksi can be specified (per ASTM Supplementary Requirement S79).
[d] If desired, minimum tensile stress of 70 ksi can be specified (per ASTM Supplementary Requirement S81).
[e] Groups 1, 2 and 3 shapes only.
[f] ASTM A618 can also be specified as corrosion-resistant; see ASTM A618.
[g] Minimum applies for walls nominally 3/4-in. thick and under. For wall thicknesses over 3/4 in., F_y = 46 ksi and F_u = 67 ksi.
[h] If desired, maximum yield stress of 65 ksi and maximum yield-to-tensile strength ratio of 0.85 can be specified (per ASTM Supplementary Requirement S75).
[i] A maximum yield-to-tensile strength ratio of 0.85 and carbon equivalent formula are included as mandatory in ASTM A992.
[j] Groups 4 and 5 shapes only.
[k] Group 3 shapes only.
[l] Groups 1 and 2 shapes only.

Table 2-2. Applicable ASTM Specifications for Plates and Bars

Steel Type	ASTM Designation		F_y Min. Yield Stress (ksi)	F_u Tensile Stress[a] (ksi)	to 0.75 incl.	over 0.75 to 1.25	over 1.25 to 1.5	over 1.5 to 2 incl.	over 2 to 2.5 incl.	over 2.5 to 4 incl.	over 4 to 5 incl.	over 5 to 6 incl.	over 6 to 8 incl.	over 8
Carbon	A36		32	58–80										
			36	58–80										
	A529	Gr. 50	50	70–100		b	b	b	b					
		Gr. 55	55	70–100		b	b							
High-Strength Low-Alloy	A572	Gr. 42	42	60										
		Gr. 50	50	65										
		Gr. 55	55	70										
		Gr. 60	60	75										
		Gr. 65	65	80										
Corrosion Resistant High-Strength Low-Alloy	A242		42	63										
			46	67										
			50	70										
	A588		42	63										
			46	67										
			50	70										
Quenched and Tempered Alloy	A514[c]		90	100–130										
			100	110–130										
Quenched and Tempered Low-Alloy	A852[c]		70	90–110										

■ = Preferred material specification.

▒ = Other applicable material specification, the availability of which should be confirmed prior to specification.

□ = Material specification does not apply.

[a] Minimum unless a range is shown.
[b] Applicable to bars only above 1-in. thickness.
[c] Available as plates only.

Table 7-8. Weight Adjustments for Combinations of Non-High-Strength Fasteners Other than Tabulated in Table 7-7

Combinations of 100		Add or Subtr.	1/4	3/8	1/2	5/8	3/4	7/8	1	1 1/8	1 1/4
			Nominal Bolt Diameter d_b, in.								
Square Bolts With	Square Nuts	+	0.1	1.0	2.0	3.4	3.5	5.5	8.0	12.2	16.3
	Heavy Square Nuts	+	0.6	2.1	4.1	7.0	11.6	17.2	23.2	32.1	41.2
	Heavy Hex Nuts	+	0.4	1.5	2.8	4.6	7.6	10.7	14.2	18.9	24.3
100 Square Bolts with Hexagonal Nuts*	Square Nuts	+	0.1	0.6	1.1	1.4	0.2	0.5	−0.2	−0.1	−1.7
	Hex Nuts	–	0.0	0.4	0.9	2.0	3.3	5.0	8.2	12.3	18.0
	Heavy Square Nuts	+	0.6	1.7	3.2	5.0	8.3	12.2	15.0	19.8	23.2
	Heavy Hex Nuts	+	0.4	1.1	1.9	2.6	4.3	5.7	6.0	6.6	6.3
100 Hex Bolts	Heavy Square Nuts	+	–	–	4.7	7.3	11.3	16.5	20.7	27.0	33.6
	Heavy Hex Nuts	+	–	–	3.4	4.9	7.3	10.0	11.7	13.8	16.7

Notes:
For weights of high-strength fasteners, see Table 7-5.
This table conforms to weight standards adopted by the Industrial Fasteners Institute (IFI).
*Add or subtract value in this table to or from the value in Table 7-7.

Table 7-9. Weights of Non-High-Strength Bolts of Diameter Greater Than 1 1/4 in., pounds

Weight of 100 Each		1 3/8	1 1/2	1 3/4	2	2 1/4	2 1/2	2 3/4	3	3 1/4	3 1/2	3 3/4	4
		Nominal Bolt Diameter d_b, in.											
Heads of:	Square Bolts	105	130	–	–	–	–	–	–	–	–	–	[illegible]
	Hex Bolts	84.0	112	178	259	369	508	680	900	1120	1390	1730	[illegible]
	Heavy Hex Bolts	95.0	124	195	280	397	541	720	950	–	–	–	[illegible]
One Linear Inch, Unthreaded Shank		42.0	50.0	68.2	89.0	113	139	168	200	235	272	313	[illegible]
One Linear Inch, Threaded Shank		35.0	42.5	57.4	75.5	97.4	120	147	178	210	246	284	[illegible]
Square Nuts		94.5	122	–	–	–	–	–	–	–	–	–	[illegible]
Heavy Square Nuts		125	161	–	–	–	–	–	–	–	–	–	[illegible]
Heavy Hex Nuts		102	131	204	299	419	564	[illegible]	950	1190	1530	1810	[illegible]

$\phi = 0.75$

Table 7-10. Design Shear Strength of One Bolt, kips

ASTM Desig.	Thread Cond.	ϕF_v (ksi)	Loading	5/8	3/4	7/8	1	1 1/8	1 1/4	1 3/8	1 1/2
				Nominal Bolt Diameter d_b, in.							
				Nominal Bolt Area, in.^{2}							
				0.307	0.442	0.601	0.785	0.994	1.23	1.48	1.77
A325 F1852	N	36.0	S	11.0	15.9	21.6	28.3	35.8	44.2	53.5	63.6
			D	22.1	31.8	43.3	56.5	71.6	88.4	107	127
	X	45.0	S	13.8	19.9	27.1	35.3	44.7	55.2	66.8	79.5
			D	27.6	39.8	54.1	70.7	89.5	110	134	159
A490	N	45.0	S	13.8	19.9	27.1	35.3	44.7	55.2	66.8	79.5
			D	27.6	39.8	54.1	70.7	89.5	110	134	159
	X	56.3	S	17.3	24.9	33.8	44.2	55.9	69.0	83.5	99.4
			D	34.5	49.7	67.6	88.4	112	138	167	199
A307	–	18.0	S	5.52	7.95	10.8	14.1	17.9	22.1	26.7	31.8
			D	11.0	15.9	21.6	28.3	35.8	44.2	53.5	63.6

N = Threads included in shear plane.
X = Threads excluded from shear plane.
S = Single shear.
D = Double shear.

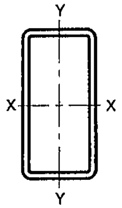
$\phi = 0.75$

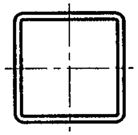
Table 7-11. Design Shear Strength of *n* Bolts, kips

n	N 3/4 S	N 3/4 D	N 7/8 S	N 7/8 D	N 1 S	N 1 D	X 3/4 S	X 3/4 D	X 7/8 S	X 7/8 D	X 1 S	X 1 D
	ASTM A325 & F1852											
12	191	382	260	520	339	679	239	477	325	649	424	848
11	175	350	238	476	311	622	219	437	298	595	389	778
10	159	318	216	433	283	565	199	398	271	541	353	707
9	143	286	195	390	254	509	179	358	244	487	318	636
8	127	254	173	346	226	452	159	318	216	433	283	565
7	111	223	152	303	198	396	139	278	189	379	247	495
6	95.4	191	130	260	170	339	119	239	162	325	212	424
5	79.5	159	108	216	141	283	99.4	199	135	271	177	353
4	63.6	127	86.6	173	113	226	79.5	159	108	216	141	283
3	47.7	95.4	64.9	130	84.8	170	59.6	119	81.2	162	106	212
2	31.8	63.6	43.3	86.6	56.5	113	39.8	79.5	54.1	108	70.7	141
1	15.9	31.8	21.6	43.3	28.3	56.5	19.9	39.8	27.1	54.1	35.3	70.7
	ASTM A490											
12	239	477	325	649	424	848	298	596	406	812	530	1060
11	219	437	298	595	389	778	273	547	372	744	486	972
10	199	398	271	541	353	707	249	497	338	676	442	884
9	179	358	244	487	318	636	224	447	304	609	398	795
8	159	318	216	433	283	565	199	398	271	541	353	707
7	139	278	189	379	247	495	174	348	237	474	309	619
6	119	239	162	325	212	424	149	298	203	406	265	530
5	99.4	199	135	271	177	353	124	249	169	338	221	442
4	79.5	159	108	216	141	283	99.4	199	135	271	177	353
3	59.6	119	81.2	162	106	212	74.6	149	101	203	133	265
2	39.8	79.5	54.1	108	70.7	141	49.7	99.4	67.6	135	88.4	177
1	19.9	39.8	27.1	54.1	35.3	70.7	24.9	49.7	33.8	67.6	44.2	88.4

N = Threads included in shear plane.

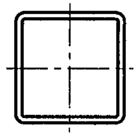
Table 1-11 (cont.). Rectangular (and Square) HSS Dimensions and Properties

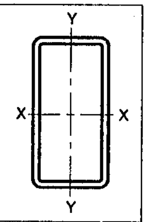




Shape	Wall Thickness, t nominal	Wall Thickness, t design	Nominal Wt.	Area, A	b/t	h/t	Axis X-X I	Axis X-X S	Axis X-X r	Axis X-X Z
	in.	in.	lb/ft	in.²			in.⁴	in.³	in.	in.³
HSS14×4	5/8	0.581	67.6	18.7	3.88	21.1	373	53.3	4.47	73.1
	1/2	0.465	55.5	15.3	5.60	27.1	317	45.3	4.55	61.0
	3/8	0.349	42.7	11.8	8.46	37.1	252	36.0	4.63	47.8
	5/16	0.291	36.0	9.92	10.7	45.1	216	30.9	4.67	40.6
	1/4	0.233	29.2	8.03	14.2	57.1	178	25.4	4.71	33.2
	3/16	0.174	22.2	6.06	20.0	77.5	137	19.5	4.74	25.3
HSS12×12	5/8	0.581	93.1	25.7	17.7	17.7	548	91.4	4.62	109
	1/2	0.465	75.9	20.9	22.8	22.8	457	76.2	4.68	89.6
	3/8	0.349	58.0	16.0	31.4	31.4	357	59.5	4.73	69.2
	5/16	0.291	48.8	13.4	38.2	38.2	304	50.7	4.76	58.6
	1/4	0.233	39.4	10.8	48.5	48.5	248	41.4	4.79	47.6
HSS12×10	1/2	0.465	69.1	19.0	18.5	22.8	395	65.9	4.56	78.8
	3/8	0.349	52.9	14.6	25.7	31.4	310	51.6	4.61	61.1
	5/16	0.291	44.6	12.2	31.4	38.2	264	44.0	4.64	51.7
	1/4	0.233	36.0	9.90	39.9	48.5	216	36.0	4.67	42.1
HSS12×8	5/8	0.581	76.1	21.0	10.8	17.7	397	66.1	4.34	82.1
	1/2	0.465	62.3	17.2	14.2	22.8	333	55.6	4.41	68.1
	3/8	0.349	47.8	13.2	19.9	31.4	262	43.7	4.47	53.0
	5/16	0.291	40.3	11.1	24.5	38.2	224	37.4	4.50	44.9
	1/4	0.233	32.6	8.96	31.3	48.5	184	30.6	4.53	36.6
	3/16	0.174	24.7	6.76	43.0	66.0	140	23.4	4.56	27.8
HSS12×6	5/8	0.581	67.6	18.7	7.33	17.7	321	53.4	4.14	68.8
	1/2	0.465	55.5	15.3	9.90	22.8	271	45.2	4.21	57.4
	3/8	0.349	42.7	11.8	14.2	31.4	215	35.9	4.28	44.8
	5/16	0.291	36.0	9.92	17.6	38.2	184	30.7	4.31	38.1
	1/4	0.233	29.2	8.03	22.8	48.5	151	25.2	4.34	31.1
	3/16	0.174	22.2	6.06	31.5	66.0	116	19.4	4.38	23.7
HSS12×4	5/8	0.581	59.1	16.4	3.88	17.7	245	40.8	3.87	55.5
	1/2	0.465	48.7	13.5	5.60	22.8	210	34.9	3.95	46.7
	3/8	0.349	37.6	10.4	8.46	31.4	168	28.0	4.02	36.7
	5/16	0.291	31.8	8.76	10.7	38.2	144	24.1	4.06	31.3
	1/4	0.233	25.8	7.10	14.2	48.5	119	19.9	4.10	25.6
	3/16	0.174	19.6	5.37	20.0	66.0	91.8	15.3	4.13	19.6
HSS12×3 1/2	3/8	0.349	36.3	10.0	7.03	31.4	156	26.0	3.94	34.7
	5/16	0.291	30.7	8.46	9.03	38.2	134	22.4	3.98	29.6
HSS12×3	5/16	0.291	29.7	8.17	7.31	38.2	124	20.7	3.90	27.9
	1/4	0.233	24.1	6.63	9.88	48.5	103	17.2	3.94	22.9
	3/16	0.174	18.3	5.02	14.2	66.0	79.6	13.3	3.98	17.5
HSS12×2	1/4	0.233	22.4	6.17	5.58	48.5	86.9	14.5	3.75	20.1
	3/16	0.174	17.1	4.67	8.49	66.0	67.4	11.2	3.80	15.5
HSS10×10	5/8	0.581	76.1	21.0	14.2	14.2	304	60.8	3.80	73.2
	1/2	0.465	62.3	17.2	18.5	18.5	256	51.2	3.86	60.7
→	3/8	0.349	47.8	13.2	25.7	25.7	202	40.4	3.92	47.2
	5/16	0.291	40.3	11.1	31.4	31.4	172	34.5	3.94	40.1
	1/4	0.233	32.6	8.96	39.9	39.9	141	28.3	3.97	32.7
	3/16	0.174	24.7	6.76	54.5	54.5	108	21.6	4.00	24.8
HSS10×8	1/2	0.465	55.5	15.3	14.2	18.5	214	42.7	3.73	51.9
	3/8	0.349	42.7	11.8	19.9	25.7	[illegible]	33.9	3.79	40.5
	5/16	0.291	36.0	9.92	24.5	31.4	[illegible]	29.0	3.82	34.4
	1/4	0.233	29.2	8.03	31.3	39.9	119	23.8	3.85	28.1
	3/16	0.174	22.2	6.06	43.0	54.5	91.4	18.3	3.88	21.4

Table 1-11 (cont.). Rectangular (and Square) HSS Dimensions and Properties





Shape	Wall Thickness, t nominal	Wall Thickness, t design	Axis Y-Y I	Axis Y-Y S	Axis Y-Y r	Axis Y-Y Z	Torsion J	Torsion C	Surface Area Per Foot
	in.	in.	in.⁴	in.³	in.	in.³	in.⁴	in.³	ft²
HSS14×4	5/8	0.581	47.2	23.6	1.59	28.5	148	52.6	2.83
	1/2	0.465	41.2	20.6	1.64	24.1	127	44.1	2.87
	3/8	0.349	33.6	16.8	1.69	19.1	102	34.6	2.90
	5/16	0.291	29.2	14.6	1.72	16.4	87.7	29.5	2.92
	1/4	0.233	24.4	12.2	1.74	13.5	72.4	24.1	2.93
	3/16	0.174	19.0	9.48	1.77	10.3	55.8	18.4	2.95
HSS12×12	5/8	0.581	548	91.4	4.62	109	885	151	3.83
	1/2	0.465	457	76.2	4.68	89.6	728	123	3.87
	3/8	0.349	357	59.5	4.73	69.2	561	94.6	3.90
	5/16	0.291	304	50.7	4.76	58.6	474	79.7	3.92
	1/4	0.233	248	41.4	4.79	47.6	384	64.5	3.93
HSS12×10	1/2	0.465	298	59.7	3.96	69.6	545	102	3.53
	3/8	0.349	234	46.9	4.01	54.0	421	78.3	3.57
	5/16	0.291	200	40.0	4.04	45.7	356	66.1	3.58
	1/4	0.233	164	32.7	4.07	37.2	289	53.5	3.60
HSS12×8	5/8	0.581	210	52.5	3.16	61.9	454	97.7	3.17
	1/2	0.465	178	44.4	3.21	51.5	377	80.4	3.20
	3/8	0.349	140	35.1	3.27	40.1	293	62.1	3.23
	5/16	0.291	120	30.1	3.29	34.1	248	52.4	3.25
	1/4	0.233	98.8	24.7	3.32	27.8	202	42.5	3.27
	3/16	0.174	75.7	18.9	3.35	21.1	153	32.2	3.28
HSS12×6	5/8	0.581	107	35.5	2.39	42.1	271	71.1	2.83
	1/2	0.465	91.1	30.4	2.44	35.2	227	59.0	2.87
	3/8	0.349	72.9	24.3	2.49	27.7	178	45.8	2.90
	5/16	0.291	62.8	20.9	2.52	23.6	152	38.8	2.92
	1/4	0.233	51.9	17.3	2.54	19.3	124	31.6	2.93
	3/16	0.174	40.0	13.3	2.57	14.7	94.6	24.0	2.95
HSS12×4	5/8	0.581	40.4	20.2	1.57	24.5	122	44.6	2.50
	1/2	0.465	35.3	17.7	1.62	20.9	105	37.5	2.53
	3/8	0.349	28.9	14.5	1.67	16.6	84.1	29.5	2.57
	5/16	0.291	25.2	12.6	1.70	14.2	72.4	25.2	2.58
	1/4	0.233	21.0	10.5	1.72	11.7	59.8	20.6	2.60
	3/16	0.174	16.4	8.20	1.75	9.00	46.1	15.7	2.62
HSS12×3 1/2	3/8	0.349	21.3	12.2	1.46	14.0	64.7	25.5	2.48
	5/16	0.291	18.6	10.6	1.48	12.1	56.0	21.8	2.50
HSS12×3	5/16	0.291	13.1	8.73	1.27	10.0	41.3	18.4	2.42
	1/4	0.233	11.1	7.38	1.29	8.28	34.5	15.1	2.43
	3/16	0.174	8.72	5.81	1.32	6.40	26.8	11.6	2.45
HSS12×2	1/4	0.233	4.41	4.41	0.845	5.08	15.1	9.64	2.27
	3/16	0.174	3.55	3.55	0.872	3.97	12.0	7.49	2.28
HSS10×10	5/8	0.581	304	60.8	3.80	73.2	498	102	3.17
	1/2	0.465	256	51.2	3.86	60.7	412	84.2	3.20
	3/8	0.349	202	40.4	3.92	47.2	320	64.8	3.23
	5/16	0.291	172	34.5	3.94	40.1	271	54.8	3.25
	1/4	0.233	141	28.3	3.97	32.7	220	44.4	3.27
	3/16	0.174	108	21.6	4.00	24.8	167	33.6	3.28
HSS10×8	1/2	0.465	151	37.8	3.14	44.5	288	66.4	2.87
	3/8	0.349	120	30.0	3.19	34.8	224	51.4	2.90
	5/16	0.291	103	25.7	3.22	29.6	190	43.5	2.92
	1/4	0.233	84.7	21.2	3.25	24.2	155	35.3	2.93
	3/16	0.174	65.1	16.3	3.28	18.4	118	26.7	2.95

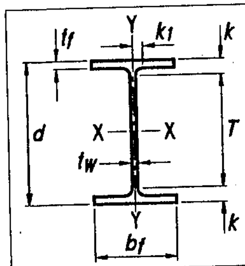
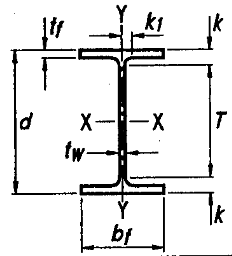


Table 1-1 (cont.). W-Shapes Dimensions

Shape	Area, A	Depth, d		Web Thickness, t_w		$\frac{t_w}{2}$	Flange Width, b_f		Flange Thickness, t_f		Distance k		k_1	T	Workable Gage†
	in.²	in.		in.		in.	in.		in.		in.	in.	in.	in.	in.
W18×71	20.8	18.5	18 1/2	0.495	1/2	1/4	7.64	7 5/8	0.810	13/16	1.21	1 1/2	7/8	15 1/2	3 1/2
×65	19.1	18.4	18 3/8	0.450	7/16	1/4	7.59	7 5/8	0.750	3/4	1.15	1 7/16	7/8		
×60	17.6	18.2	18 1/4	0.415	7/16	1/4	7.56	7 1/2	0.695	11/16	1.10	1 3/8	13/16		
×55	16.2	18.1	18 1/8	0.390	3/8	3/16	7.53	7 1/2	0.630	5/8	1.03	1 5/16	13/16		
×50	14.7	18.0	18	0.355	3/8	3/16	7.50	7 1/2	0.570	9/16	0.972	1 1/4	13/16		
W18×46	13.5	18.1	18	0.360	3/8	3/16	6.06	6	0.605	5/8	1.01	1 1/4	13/16	15 1/2	3 1/2
×40	11.8	17.9	17 7/8	0.315	5/16	3/16	6.02	6	0.525	1/2	0.927	1 3/16	13/16		
×35	10.3	17.7	17 3/4	0.300	5/16	3/16	6.00	6	0.425	7/16	0.827	1 1/8	3/4		
W16×100	29.7	17.0	17	0.585	9/16	5/16	10.4	10 3/8	0.985	1	1.69	1 7/8	1 1/8	13 1/4	5 1/2
×89	26.4	16.8	16 3/4	0.525	1/2	1/4	10.4	10 3/8	0.875	7/8	1.58	1 3/4	1 1/16		
×77	22.9	16.5	16 1/2	0.455	7/16	1/4	10.3	10 1/4	0.760	3/4	1.47	1 5/8	1 1/16		
×67	20.0	16.3	16 3/8	0.395	3/8	3/16	10.2	10 1/4	0.665	11/16	1.37	1 9/16	1		
W16×57	16.8	16.4	16 3/8	0.430	7/16	1/4	7.12	7 1/8	0.715	11/16	1.12	1 3/8	7/8	13 5/8	3 1/2
×50	14.7	16.3	16 1/4	0.380	3/8	3/16	7.07	7 1/8	0.630	5/8	1.03	1 5/16	13/16		
×45	13.3	16.1	16 1/8	0.345	3/8	3/16	7.04	7	0.565	9/16	0.967	1 1/4	13/16		
×40	11.8	16.0	16	0.305	5/16	3/16	7.00	7	0.505	1/2	0.907	1 3/16	13/16		
×36	10.6	15.9	15 7/8	0.295	5/16	3/16	6.99	7	0.430	7/16	0.832	1 1/8	3/4		
W16×31	9.13	15.9	15 7/8	0.275	1/4	1/8	5.53	5 1/2	0.440	7/16	0.842	1 1/8	3/4	13 5/8	3 1/2
×26	7.68	15.7	15 3/4	0.250	1/4	1/8	5.50	5 1/2	0.345	3/8	0.747	1 1/16	3/4	13 5/8	3 1/2
W14×808*	237	22.8	22 7/8	3.74	3 3/4	1 7/8	18.6	18 1/2	5.12	5 1/8	5.72	6 7/16	3 1/16	10	3–7 1/2-3
×730*	215	22.4	22 3/8	3.07	3 1/16	1 9/16	17.9	17 7/8	4.91	4 15/16	5.51	6 3/16	2 3/4		3–7 1/2-3
×665*	196	21.6	21 5/8	2.83	2 13/16	1 7/16	17.7	17 5/8	4.52	4 1/2	5.12	5 13/16	2 5/8		
×605*	178	20.9	20 7/8	2.60	2 5/8	1 5/16	17.4	17 3/8	4.16	4 3/16	4.76	5 7/16	2 1/2		
×550*	162	20.2	20 1/4	2.38	2 3/8	1 3/16	17.2	17 1/4	3.82	3 13/16	4.42	5 1/8	2 3/8		
×500*	147	19.6	19 5/8	2.19	2 3/16	1 1/8	17.0	17	3.50	3 1/2	4.10	4 13/16	2 5/16		
×455*	134	19.0	19	2.02	2	1	16.8	16 7/8	3.21	3 3/16	3.81	4 1/2	2 1/4		
×426*	125	18.7	18 5/8	1.88	1 7/8	15/16	16.7	16 3/4	3.04	3 1/16	3.63	4 5/16	2 1/8		
×398*	117	18.3	18 1/4	1.77	1 3/4	7/8	16.6	16 5/8	2.85	2 7/8	3.44	4 1/8	2 1/8		
×370*	109	17.9	17 7/8	1.66	1 5/8	13/16	16.5	16 1/2	2.66	2 11/16	3.26	3 15/16	2 1/16		
×342*	101	17.5	17 1/2	1.54	1 9/16	13/16	16.4	16 3/8	2.47	2 1/2	3.07	3 3/4	2		
×311*	91.4	17.1	17 1/8	1.41	1 7/16	3/4	16.2	16 1/4	2.26	2 1/4	2.86	3 9/16	1 15/16		
×283*	83.3	16.7	16 3/4	1.29	1 5/16	11/16	16.1	16 1/8	2.07	2 1/16	2.67	3 3/8	1 7/8		
×257*	75.6	16.4	16 3/8	1.18	1 3/16	5/8	16.0	16	1.89	1 7/8	2.49	3 3/16	1 13/16		
×233*	68.5	16.0	16	1.07	1 1/16	9/16	15.9	15 7/8	1.72	1 3/4	2.32	3	1 3/4		
×211	62.0	15.7	15 3/4	0.980	1	1/2	15.8	15 3/4	1.56	1 9/16	2.16	2 7/8	1 11/16		
×193	56.8	15.5	15 1/2	0.890	7/8	7/16	15.7	15 3/4	1.44	1 7/16	2.04	2 3/4	1 11/16		
×176	51.8	15.2	15 1/4	0.830	13/16	7/16	15.7	15 5/8	1.31	1 5/16	1.91	2 5/8	1 5/8		
×159	46.7	15.0	15	0.745	3/4	3/8	15.6	15 5/8	1.19	1 3/16	1.79	2 1/2	1 9/16		
×145	42.7	14.8	14 3/4	0.680	11/16	3/8	15.5	15 1/2	1.09	1 1/16	1.69	2 3/8	1 9/16		
W14×132	38.8	14.7	14 5/8	0.645	5/8	5/16	14.7	14 3/4	1.03	1	1.63	2 5/16	1 9/16	10	5 1/2
×120	35.3	14.5	14 1/2	0.590	9/16	5/16	14.7	14 5/8	0.940	15/16	1.54	2 1/4	1 1/2		
×109	32.0	14.3	14 3/8	0.525	1/2	1/4	14.6	14 5/8	0.860	7/8	1.46	2 3/16	1 1/2		
×99	29.1	14.2	14 1/8	0.485	1/2	1/4	14.6	14 5/8	0.780	3/4	1.38	2 1/16	1 7/16		
×90	26.5	14.0	14	0.440	7/16	1/4	14.5	14 1/2	0.710	11/16	1.31	2	1 7/16		
W14×82	24.0	14.3	14 1/4	0.510	1/2	1/4	10.1	10 1/8	0.855	7/8	1.45	1 11/16	1 1/16	10 7/8	5 1/2
×74	21.8	14.2	14 1/8	0.450	7/16	1/4	10.1	10 1/8	0.785	13/16	1.38	1 5/8	1 1/16		
×68	20.0	14.0	14	0.415	7/16	1/4	10.0	10	0.720	3/4	1.31	[illegible]	1 1/16		
×61	17.9	13.9	13 7/8	0.375	3/8	3/16	9.99	10	0.645	5/8	1.24	[illegible]	1		
W14×53	15.6	13.9	13 7/8	0.370	3/8	3/16	8.06	8	0.660	11/16	1.25	1 1/2	1	10 7/8	5 1/2

Table 1-1 (cont.). W-Shapes Properties



Nominal Wt.	Compact Section Criteria $\frac{b_f}{2t_f}$	$\frac{h}{t_w}$	F_y'''	X_1	$X_2 \times 10^6$	Axis X-X I	S	r	Z	Axis Y-Y I	S	r	Z
lb/ft			ksi	ksi	(1/ksi)²	in.⁴	in.³	in.	in.³	in.⁴	in.³	in.	in.³
71	4.71	32.4	61.3	2690	3290	1170	127	7.50	146	60.3	15.8	1.70	24.7
65	5.06	35.7	50.6	2470	4540	1070	117	7.49	133	54.8	14.4	1.69	22.5
60	5.44	38.7	43.1	2290	6080	984	108	7.47	123	50.1	13.3	1.68	20.6
55	5.98	41.1	38.0	2110	8540	890	98.3	7.41	112	44.9	11.9	1.67	18.5
50	6.57	45.2	31.5	1920	12400	800	88.9	7.38	101	40.1	10.7	1.65	16.6
46	5.01	44.6	32.4	2060	10100	712	78.8	7.25	90.7	22.5	7.43	1.29	11.7
40	5.73	50.9	24.8	1810	17200	612	68.4	7.21	78.4	19.1	6.35	1.27	9.95
35	7.06	53.5	22.5	1590	30800	510	57.6	7.04	66.5	15.3	5.12	1.22	8.06
100	5.29	23.2	–	3530	947	1500	177	7.10	200	186	35.7	2.50	55.0
89	5.92	25.9	–	3160	1460	1310	157	7.05	177	163	31.4	2.48	48.2
77	6.77	29.9	–	2770	2460	1120	136	7.00	152	138	26.9	2.46	41.2
67	7.70	34.4	54.5	2440	4040	970	119	6.97	132	119	23.2	2.44	35.6
57	4.98	33.0	59.1	2650	3400	758	92.2	6.72	105	43.1	12.1	1.60	18.9
50	5.61	37.4	46.1	2340	5530	659	81.0	6.68	92.0	37.2	10.5	1.59	16.3
45	6.23	41.1	38.0	2120	8280	586	72.7	6.65	82.3	32.8	9.34	1.57	14.5
40	6.93	46.5	29.7	1890	12700	518	64.7	6.63	73.0	28.9	8.25	1.57	12.7
36	8.12	48.1	27.8	1700	20400	448	56.5	6.51	64.0	24.5	7.00	1.52	10.8
31	6.28	51.6	24.2	1740	19900	375	47.2	6.41	54.0	12.4	4.49	1.17	7.03
26	7.97	56.8	20.0	1480	40300	301	38.4	6.26	44.2	9.59	3.49	1.12	5.48
808	1.81	3.05	–	18900	1.45	16000	1400	8.20	1830	5510	594	4.82	927
730	1.82	3.71	–	17500	1.90	14300	1280	8.17	1660	4720	527	4.69	816
665	1.95	4.03	–	16300	2.46	12400	1150	7.98	1480	4170	472	4.62	730
605	2.09	4.39	–	15100	3.21	10800	1040	7.80	1320	3680	423	4.55	652
550	2.25	4.79	–	14200	4.16	9430	931	7.63	1180	3250	378	4.49	583
500	2.43	5.21	–	13100	5.49	8210	838	7.48	1050	2880	339	4.43	522
455	2.62	5.66	–	12200	7.30	7190	756	7.33	936	2560	304	4.38	468
426	2.75	6.08	–	11500	8.87	6600	706	7.26	869	2360	283	4.34	434
398	2.92	6.44	–	10900	11.0	6000	656	7.16	801	2170	262	4.31	402
370	3.10	6.89	–	10300	13.9	5440	607	7.07	736	1990	241	4.27	370
342	3.31	7.41	–	9620	17.8	4900	558	6.98	672	1810	221	4.24	338
311	3.59	8.09	–	8820	24.4	4330	506	6.88	603	1610	199	4.20	304
283	3.89	8.84	–	8120	33.4	3840	459	6.79	542	1440	179	4.17	274
257	4.23	9.71	–	7460	46.1	3400	415	6.71	487	1290	161	4.13	246
233	4.62	10.7	–	6820	64.9	3010	375	6.63	436	1150	145	4.10	221
211	5.06	11.6	–	6230	91.8	2660	338	6.55	390	1030	130	4.07	198
193	5.45	12.8	–	5740	125	2400	310	6.50	355	931	119	4.05	180
176	5.97	13.7	–	5280	173	2140	281	6.43	320	838	107	4.02	163
159	6.54	15.3	–	4780	252	1900	254	6.38	287	748	96.2	4.00	146
145	7.11	16.8	–	4400	348	1710	232	6.33	260	677	87.3	3.98	133
132	7.15	17.7	–	4180	428	1530	209	6.28	234	548	74.5	3.76	113
120	7.80	19.3	–	3830	601	1380	190	6.24	212	495	67.5	3.74	102
109	8.49	21.7	–	3490	853	1240	173	6.22	192	447	61.2	3.73	92.7
99	9.34	23.5	–	3190	1220	1110	157	6.17	173	402	55.2	3.71	83.6
90	10.20	25.9	–	2900	1750	999	143	6.14	157	362	49.9	3.70	75.6
82	5.92	22.4	–	3590	849	881	123	6.05	139	148	29.3	2.48	44.8
74	6.41	25.4	–	3280	1200	795	112	6.04	126	134	26.6	2.48	40.5
68	6.97	27.5	[illegible]	3020	1660	722	103	6.01	115	121	24.2	2.46	36.9
61	7.75	30.4	[illegible]	2720	2470	640	92.1	5.98	102	107	21.5	2.45	32.8
53	6.11	30.9	–	2830	2250	541	77.8	5.89	87.1	57.7	14.3	1.92	22.0
48	6.75	33.6	57.1	2580	3250	484	70.2	5.85	78.4	51.4	12.8	1.91	19.6

Z_x

Table 5-3 (cont.). W-Shapes Selection by Z_x

$F_y = 50$ ksi
$\phi_b = 0.90$
$\phi_v = 0.90$

Shape	Z_x	I_x	$\phi_b M_{px}$	$\phi_b M_{rx}$	L_p	L_r	BF	$\phi_v V_n$	Z_y	I_y	$\phi_b M_{py}$
	X-X Axis								Y-Y Axis		
	in.^{3}	in.^{4}	kip-ft	kip-ft	ft	ft	kips	kips	in.^{3}	in.^{4}	kip-ft
W27×84	**244**	**2850**	**915**	**639**	**7.31**	**19.3**	**23.0**	**332**	**33.2**	**106**	**119**
W12×152	243	1430	911	627	11.3	62.1	5.59	322	111	454	410
W14×132	234	1530	878	627	13.3	49.7	6.88	256	113	548	419
W18×106	230	1910	863	612	9.40	28.7	13.0	298	60.5	220	222
W24×84	**224**	**2370**	**840**	**588**	**6.89**	**18.6**	**21.5**	**306**	**32.6**	**94.4**	**118**
W21×93	221	2070	829	576	6.50	19.3	19.7	338	34.7	92.9	124
W12×136	214	1240	803	558	11.2	55.7	5.49	286	98.0	398	361
W14×120	212	1380	795	570	13.2	46.3	6.81	231	102	495	380
W18×97	211	1750	791	564	9.36	27.5	12.6	269	55.3	201	203
W24×76	**200**	**2100**	**750**	**528**	**6.78**	**18.0**	**19.8**	**284**	**28.6**	**82.5**	**103**
W16×100	199	1490	746	528	8.87	29.5	10.6	269	54.9	186	201
W21×83	196	1830	735	513	6.46	18.5	18.5	298	30.5	81.4	110
W14×109	192	1240	720	519	13.2	43.2	6.69	203	92.7	447	344
W18×86	186	1530	698	498	9.29	26.0	11.9	238	48.4	175	178
W12×120	186	1070	698	489	11.1	50.0	5.36	251	85.4	345	315
W24×68	**177**	**1830**	**664**	**462**	**6.61**	**17.4**	**18.6**	**266**	**24.5**	**70.4**	**88.3**
W16×89	176	1310	660	468	8.80	27.5	10.3	238	48.2	163	177
W14×99††	173	1110	649	471	13.5	40.6	6.56	186	83.6	402	311
W21×73	172	1600	645	453	6.39	17.6	17.1	260	26.6	70.6	95.6
W12×106	164	933	615	435	11.0	44.9	5.31	212	75.1	301	277
W18×76	163	1330	611	438	9.22	24.8	11.1	209	42.2	152	155
W21×68	**160**	**1480**	**600**	**420**	**6.36**	**17.3**	**16.5**	**245**	**24.4**	**64.7**	**88.3**
W14×90††	157	999	589	429	15.1	38.4	6.85	166	75.6	362	281
W24×62	**154**	**1560**	**578**	**396**	**4.84**	**13.3**	**21.6**	**275**	**15.8**	**34.5**	**55.1**
W16×77	151	1120	566	405	8.69	25.3	9.68	203	41.2	138	151
W12×96	147	833	551	393	10.9	41.3	5.20	189	67.5	270	250
W10×112	147	716	551	378	9.47	56.5	3.68	232	69.2	236	255
W18×71	146	1170	548	381	6.00	17.8	14.1	247	24.7	60.3	88.9
W21×62	**144**	**1330**	**540**	**381**	**6.25**	**16.7**	**15.2**	**227**	**21.7**	**57.5**	**78.8**
W14×82	139	882	521	369	8.76	29.6	7.30	197	44.8	148	165
W24×55	**135**	**1360**	**506**	**345**	**4.73**	**12.9**	**19.8**	**252**	**13.4**	**29.1**	**46.7**
W18×65	133	1070	499	351	5.97	17.1	13.3	224	22.5	54.8	81.0
W12×87	132	740	495	354	10.8	38.4	5.13	174	60.4	241	223
W16×67	131	963	491	354	8.65	23.8	9.04	174	35.5	119	131
W10×100	130	623	488	336	9.36	50.8	3.66	204	61.0	207	225
W21×57	129	1170	484	333	4.77	13.2	17.8	231	14.9	30.7	52.6

†† Indicates flange is non-compact.

$F_y = 50$ ksi
$\phi_b = 0.90$
$\phi_v = 0.90$

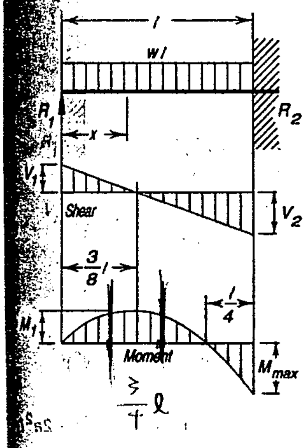
Table 5-3 (cont.). W-Shapes Selection by Z_x

Z_x

Shape	Z_x	I_x	$\phi_b M_{px}$	$\phi_b M_{rx}$	L_p	L_r	BF	$\phi_v V_n$	Z_y	I_y	$\phi_b M_{py}$
	X-X Axis								Y-Y Axis		
	in.^{3}	in.^{4}	kip-ft	kip-ft	ft	ft	kips	kips	in.^{3}	in.^{4}	kip-ft
W21×55	126	1140	473	330	6.11	16.1	14.3	211	18.4	48.4	66.4
W14×74	126	796	473	336	8.76	27.9	7.12	173	40.5	134	150
W18×60	123	984	461	324	5.93	16.6	12.9	204	20.6	50.1	74.8
W12×79	119	662	446	321	10.8	35.7	5.03	157	54.3	216	201
W14×68	115	722	431	309	8.69	26.4	6.91	157	36.9	121	136
W10×88	113	534	424	296	9.29	45.1	3.58	176	53.1	179	196
W18×55	**112**	**890**	**420**	**295**	**5.90**	**16.1**	**12.2**	**191**	**18.5**	**44.9**	**66.9**
W21×50	**111**	**989**	**416**	**285**	**4.59**	**12.5**	**16.5**	**213**	**12.2**	**24.9**	**43.0**
W12×72	108	597	405	292	10.7	33.6	4.93	143	49.2	195	182
W21×48††	**107**	**959**	**401**	**279**	**6.09**	**15.4**	**13.2**	**195**	**14.9**	**38.7**	**53.5**
W16×57	105	758	394	277	5.65	16.6	10.7	190	18.9	43.1	68.1
W14×61	102	640	383	277	8.65	25.0	6.50	141	32.8	107	121
W18×50	101	800	379	267	5.83	15.6	11.5	173	16.6	40.1	60.2
W10×77	97.6	455	366	258	9.18	39.9	3.53	152	45.9	154	169
W12×65††	96.8	533	363	264	11.9	31.7	5.01	127	44.1	174	164
W21×44	**95.8**	**847**	**359**	**246**	**4.45**	**12.0**	**15.0**	**196**	**10.2**	**20.7**	**35.8**
W16×50	92.0	659	345	243	5.62	15.7	10.1	167	16.3	37.2	59.1
W18×46	90.7	712	340	236	4.56	12.6	12.9	176	11.7	22.5	41.8
W14×53	87.1	541	327	233	6.78	20.1	7.01	139	22.0	57.7	80.4
W12×58	86.4	475	324	234	8.87	27.0	4.97	119	32.5	107	120
W10×68	85.3	394	320	227	9.15	36.0	3.45	132	40.1	134	149
W16×45	82.3	586	309	218	5.55	15.1	9.46	150	14.5	32.8	52.5
W18×40	**78.4**	**612**	**294**	**205**	**4.49**	**12.0**	**11.7**	**152**	**9.95**	**19.1**	**35.7**
W14×48	78.4	485	294	211	6.75	19.2	6.70	127	19.6	51.4	72.0
W12×53	77.9	425	292	212	8.76	25.6	4.78	113	29.1	95.8	108
W10×60	74.6	341	280	200	9.08	32.6	3.39	116	35.0	116	129
W16×40	**73.0**	**518**	**274**	**194**	**5.55**	**14.7**	**8.71**	**132**	**12.7**	**28.9**	**46.4**
W12×50	71.9	391	270	193	6.92	21.5	5.30	122	21.3	56.3	78.2
W14×43	69.6	428	261	188	6.68	18.2	6.31	113	17.3	45.2	63.6
W10×54	66.6	303	250	180	9.04	30.2	3.30	101	31.3	103	116
W18×35	**66.5**	**510**	**249**	**173**	**4.31**	**11.5**	**10.7**	**143**	**8.06**	**15.3**	**28.8**
W12×45	64.2	348	241	173	6.89	20.3	5.06	109	19.0	50.0	69.8
W16×36	64.0	448	240	170	5.37	14.1	8.11	127	10.8	24.5	39.4
W14×38	61.1	383	229	163	5.47	14.9	7.05	118	12.1	26.7	44.3
W10×49	60.4	272	227	164	8.97	28.3	3.24	91.6	28.3	93.4	105
W12×40	57.0	307	214	155	6.85	19.2	4.79	94.8	16.8	44.1	61.9
W10×45	54.9	248	206	147	7.10	24.1	3.44	95.4	20.3	53.4	74.8
W14×34	**54.2**	**337**	**203**	**145**	**5.40**	**14.3**	**6.58**	**108**	**10.6**	**23.3**	**38.9**

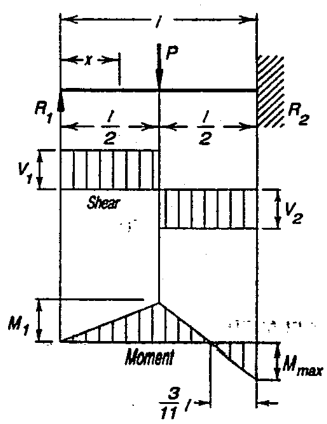
†† Indicates flange is non-compact.

12. BEAM FIXED AT ONE END, SUPPORTED AT OTHER—UNIFORMLY DISTRIBUTED LOAD



Total Equiv. Uniform Load		$= wl$
$R_1 = V_1$		$= \frac{3wl}{8}$
$R_2 = V_{2\,max}$		$= \frac{5wl}{8}$
V_x		$= R_1 - wx$
M_{max}		$= \frac{wl^2}{8}$
M_x	$\left(\text{at } x = \frac{3}{8}l\right)$	$= \frac{9}{128}wl^2$
M_x		$= R_1 x - \frac{wx^2}{2}$
Δ_{max}	$\left(\text{at } x = \frac{l}{16}(1+\sqrt{33}) = 0.4221\right)$	$= \frac{wl^4}{185EI}$
Δ_x		$= \frac{wx}{48EI}(l^3 - 3lx^2 + 2x^3)$

13. BEAM FIXED AT ONE END, SUPPORTED AT OTHER—CONCENTRATED LOAD AT CENTER



Total Equiv. Uniform Load		$= \frac{3P}{2}$
$R_1 = V_1$		$= \frac{5P}{15}$
$R_2 = V_{2\,max}$		$= \frac{11P}{16}$
M_{max} (at fixed end)		$= \frac{3Pl}{16}$
M_1	(at point of load)	$= \frac{5Pl}{32}$
M_x	$\left(\text{when } x < \frac{l}{2}\right)$	$= \frac{5Px}{16}$
M_x	$\left(\text{when } x > \frac{l}{2}\right)$	$= P\left(\frac{l}{2} - \frac{11x}{16}\right)$
Δ_{max}	$\left(\text{at } x = l\sqrt{\frac{1}{5}} = 0.447l\right)$	$= \frac{Pl^3}{48EI\sqrt{5}} = 0.00932\frac{Pl^3}{EI}$
Δ_x	(at point of load)	$= \frac{7PL^3}{768EI}$
Δ_x	$\left(\text{when } x < \frac{l}{2}\right)$	$= \frac{Px}{96EI}(3l^2 - 5x^2)$
Δ_x	$\left(\text{when } x > \frac{l}{2}\right)$	$= \frac{P}{96EI}(x-l)^2(11x - 2l)$