THE OPEN UNIVERSITY OF SRI LANKA
Department of Civil Engineering
Bachelor of Technology (Civil) - Level 6

032

CEX6332/CEU4306 – Structural Design

FINAL EXAMINATION - 2005

Time Allowed: Four (04) Hours.

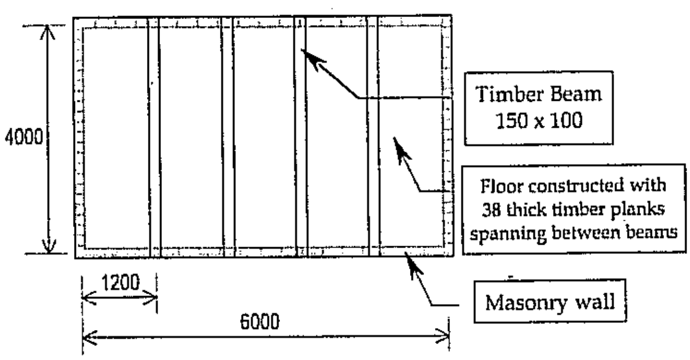
Date: 2006 - 04 - 29 Time: 0930 - 1330 hrs.

Paper consists of five (05) questions. Answer any four (04) questions.
You may use the booklet named "Extracts From Relevant Standards" provided to you with the course material
You may assume and state reasonable values for any factors not provided.

Q1. Timber Design

Q1 - Part A

An office room is to be constructed over an existing garage in a proposed domestic extention. The garage is an independent rectangular building constructed with 225 thick masonry walls, as shown in the figure. To minimise inconveniences caused during construction, the Engineer advising on this work proposed a timber floor.



Plan of the proposed timber floor

Timber - Balau
Strength Class - SC8

Dead loads on the floor:
Weight of finishes - 0.3 kN/m^2
Unit weight of planks - 8.0 kN/m^3
Unit weight of Balau - 10.8 kN/m^3

Imposed loads on the floor:
under normal service - 1.5 kN/m^2

Assume:
* Exposure condition is wet.
* lateral support at the ends of the beams due to embedment in the masonry walls.
* Loads are medium term.
* Maximum allowable deflection for the beam is 25 mm at mid span.

All dimensions are in 'mm'

The floor layout consists of timber planks supported by timber beams which are simply supported on existing masonry walls as shown .Effective span of a timber beam is 4.0 m and they are spaced at 1.2 m.

i.) Evaluate the loading on the beam due to **live and dead** loads.
(02 marks)

ii.) Check the proposed beam against **lateral stability** criteria.
(02 marks)

iii.) Compute the applied **bending stress** at the critical section and check whether this is within the permissible limit.
(02 marks)

iv.) Check whether the **maximum allowable deflection** is within the permissible limit.
You may use the following deflection values at mid span of a simply supported beam loaded with an udl;
Deflection due to Bending $= 5wL^4 / (384EI)$
Deflection due to Shear $= 3wL^2 / (20GA)$
(03 marks)

v.) Check whether the beam is safe against failure due to **shear**.
(03 marks)

vi.) Check whether applied **bearing stress** is within the permissible limit. Assume that wane is permitted at bearing area.
(03 marks)

Q1 - Part B

The table given below shows the description of two elements; AB and BE of a cantilevering Timber truss supporting an out-door canopy. The two elements can be assumed to only deflect in the plane of the truss.

Element	Length (m)	Magnitude of force (kN)	Magnitude of Moment (kNm)
AB	2.5	22 (tensile)	3.2
BE	2.8	28 (compressive)	3.8

Timber members of strength class 9 (SC 9) with cross sectional dimensions of 150 mm x 75 mm are proposed for both elements. The frame is subject to wet exposure conditions. All loads acting on the frame are of medium term duration.

i.) Determine the adequacy of member AB to carry the combined tensile force and moment.
(05 marks)

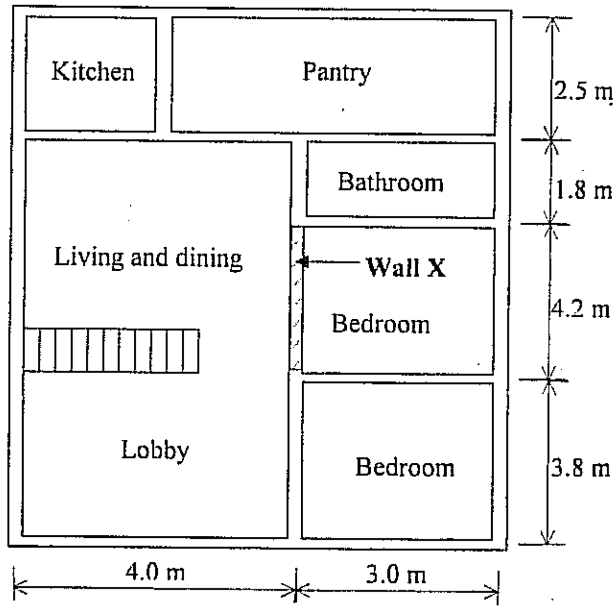
ii.) Determine the adequacy of member BE to carry the combined compressive force and moment.
(05 marks)

Q2. Masonry Design

The diagram below shows the proposed ground plan for a typical two storey house for a real estate developer. To lower the cost of construction, the Structural Engineer who designed the layout wishes to know whether brick walls are suitable as load bearing walls. Using the loads on the wall given to you, design the 3.0 m high Wall A on the ground floor.

dead load by roof structure	= 3.3 kN/m
dead load by ceiling structure	= 1.1 kN/m
dead load by upper floor slab	= 15.0 kN/m
imposed load by roof structure	= 1.5 kN/m
imposed load by ceiling structure	= 0.2 kN/m
imposed load by upper floor slab	= 12.0 kN/m

Compressive strength of local bricks:
Grade I - 4.5 N/mm²
Grade II - 2.5 N/mm²
Grade III - 1.8 N/mm²
maximum water absorption = 28%



Typical Floor Plan

You may also use the following data;

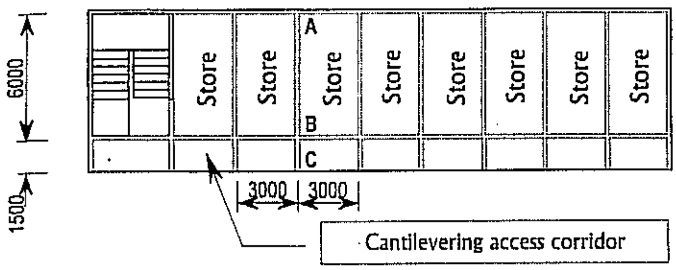
- Normal Manufacturing and Construction controls are applicable
- Assume that the forces due to wind are negligible
- The wall to be plastered on both sides with 15mm thick plaster (weight = 0.3 kN/m²)
- Dimensions of locally available bricks: 215 mm x 102.5 mm x 65 mm and with the 10mm mortar joint size changes to 225 mm 112.5 mm x75 mm, structural thickness of the wall is 225 mm, and Density of brickwork is 2300 kg/m³.

i.) Determine the usability of locally available bricks to construct the Wall A assuming a suitable mortar designation.
(20 Marks)

ii.) Compute the magnitude of shear resistance of Wall A in the longitudinal direction.
(05 Marks)

Q3. Reinforced Concrete Design

Three storied commercial buildings are needed in conjested Colombo city limits to house small retail stores. Design Engineers of CMC has proposed a building layout as depicted by a typical upper floor plan in the sketch below. Reinforced concrete framed structural system is to be adopted with infill walls out of 100 mm thick masonry to seperate stores. Beam grid is to be supported on columns at intersections except the 1500 mm cantilevering beam extention supporting the corridor.



Upper Floor Plan of the proposed building

Loads on the structure;	
Dead load of the Roof	= 1.5 kN/m^2
Imposed load on the roof	= neglect
Imposed load on floors	= 3.0 kN/m^2
** You may neglect the effects of Wind	
Thickness of floor slab	= 125 mm
Storey height (floor to floor)	= 3.0 m
Weights of materials	
Unit weight of RC	= 24.0 kN/m^3
Unit weight of Masonry	= 18.0 kN/m^3

Strength of materials;	
Grade of concrete	= 30
Characteristic strength of steel Main r/f	= 460 N/mm^2
Shear r/f	= 250 N/mm^2

Other parameters;
Condition of exposure = Mild
Center to center dimensions are given for the grid
Order of floors – Ground, 1st, 2nd
Service stress = Design Stress / 1.5 (for footing design)
Required design charts are provided
All Dimensions are in 'mm'

Follow the steps below in the design checks and design.

i.) Identify the different slab panels in the upper floor slab (except in the **stairwell** area) and check the adequacy of 125 mm thickness for each of these panels based on the **deflection criterion** only. You <u>need not</u> do any modifications. (You may assume that the slabs are continuous with the supporting beams & a suitable value for M/bd^2 for the expected loading).

(05 marks)

ii.) Identify the most critical slab panel for a upper floor slab and design it using the approach given in BS8110. In the design process you should check for satisfying the Ultimate Limit State of Flexure and Serviceability Limit States of Durability, Fire resistance, Cracking and Deflection.

(05 marks)

iii.) Evaluate the Characteristic and Design loads and tabulate Design **Bending moments** and **Shear forces** at **Critical** sections of the reinforced concrete transverse beam **ABC** (450 x 300 mm). (You may assume that beam is simply supported at A & B with a cantilevered end at C and the loads transferred to the beam are uniformly distributed along its span.

(05 marks)

iv.) Design reinforcement for the two spans of the above beam at critical sections to resist bending and shear forces. (Assume 20 mm bars for main reinforcement and 6 mm MS bars for shear reinforcement.). Curtail the beam reinforcement using simplified rules and sketch elevation and necessary cross sections in compliance with the standard method of detailing.

(05 marks)

v.) Assuming the column at B (250 x 250), is **unbraced** and <u>no</u> bending moments are transferred from beams framing in to the column, evaluate the slenderness condition, the **Design axial load** and generated **Bending moments** (if any), and design reinforcement for the column segment between 1st floor and 2nd floor. Sketch elevation and required cross sections using the standard method of detailing.

(05 marks)

Q4. Steel Design

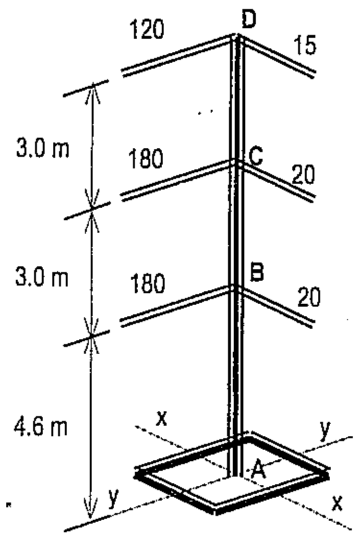
A corner column of a three-storey building is shown in the figure below. The design loads indicated in kN on each beam are the end reactions from beams. Beams are connected to the column with eccentric pin-joints.

Assuming a grade 43 steel Universal Column (UC) section (H – section) 203 x 203 of adequate weight, determine the bending moments in the column with respect to major axis x-x and minor axis y-y, just above and just below the first floor level (connection B).

(10 marks)

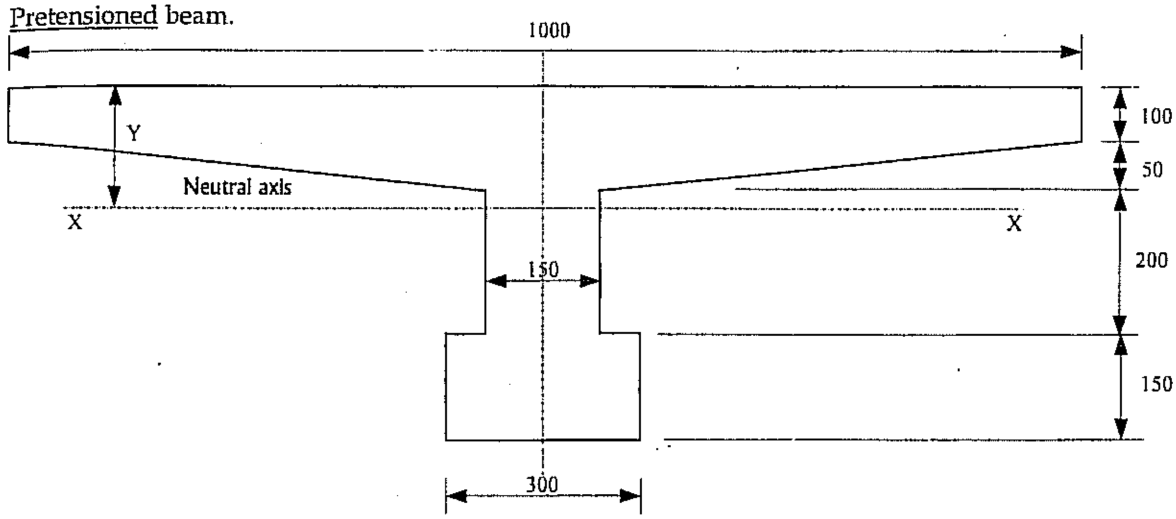
Using simplified approach check whether the assumed column section AB can withstand the applied loads. If not, design a suitable section. (Section properties for standard sizes of H sections are provided at the end of the paper)

(15 marks)



Q5. Prestressed Concrete Design

Wide flanged 'T' sections are generally used for lightly loaded bridge beams and large span building floor beams. Such sectioned prestressed beam was proposed by the Chief Design Engineer of concrete precast element production unit of the SEC. Cross section of the proposed beam is shown in the diagram below. There is a demand in the market for such beam/slab elements in the range of 15.0 m simply supported span. Based on the structural and economic considerations the beam is to be a <u>Class 2 Pretensioned</u> beam.



By preliminary calculations the section for the prestressed beam, material properties and the probable loading on the slab are taken as follows;

Strengths

f_{cu} at 28 days = 50 MPa
f_{ci} at 7 days (transfer) = 35 MPa
Transfer is 7 day after casting
f_{pu} Super strand 11.3 mm dia. tendons (Area 75 mm^2) = 1860 MPa

Allowable concrete stresses for class 2 members

at transfer;
f'_{max} = 17.5 MPa
f'_{min} = - 2.7 MPa
at service;
f_{max} = 16.7 MPa
f_{min} = - 3.2 MPa

Loads

Weight of concrete = 24 kN/m^3
Imposed load = 4.0 kN/m^2
(loads are distributed evenly.)

Loss of prestress

at transfer = 07 %
at service = 22 %

Concrete section properties

A_c = 204 x 10^3 mm^2
I_{xx} = 4.9 x 10^9 mm^4
y_{na} = 172 mm

You may use following inequalities (in standard notation)

$Z_t \geq (\alpha M_s - \beta M_i) / (\alpha f_{max} - \beta f'_{min})$
$Z_b \geq (\alpha M_s - \beta M_i) / (\beta f'_{max} - \alpha f_{min})$

$P_i \geq (Z_t f'_{min} - M_i) \ / \ \alpha(Z_t/A_c - e)$
$P_i \leq (Z_b f'_{max} + M_i) \ / \ \alpha(Z_b/A_c + e)$
$P_i \leq (Z_t f_{max} - M_s) \ / \ \beta(Z_t/A_c - e)$
$P_i \geq (Z_b f_{min} + M_s) \ / \ \beta(Z_b/A_c + e)$

Using above data, design the beam along the following steps;

i.) Evaluate the section properties (A, I, Z_t & Z_b) of the beam and check against the given values where applicable.
(03 marks)

ii.) Evaluate the dead and imposed loads on the beam at transfer and in service and calculate the critical bending moments at the two instances. (Assume that the beam is kept in the same orientation at casting and in service.).
(03 marks)

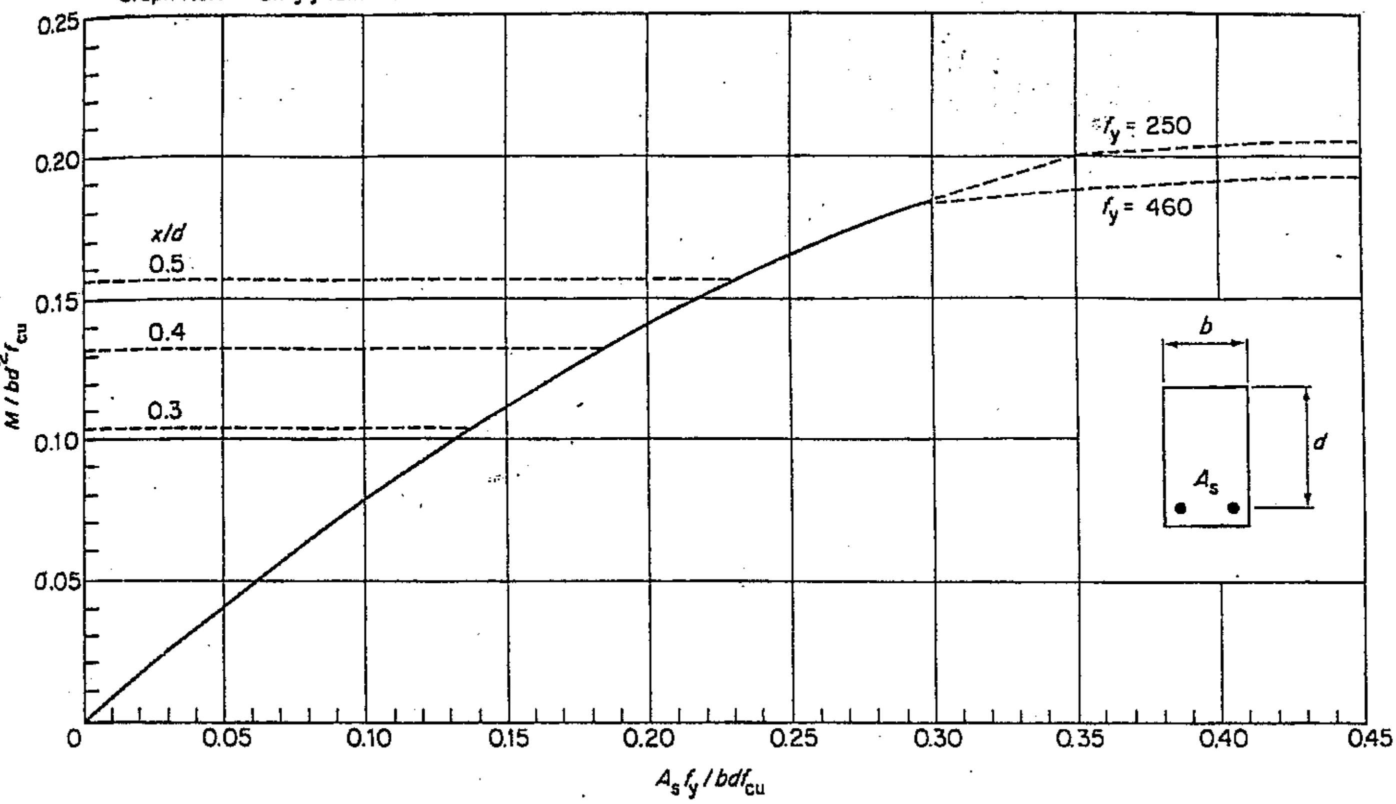
iii.) Check the adequacy of the section in carrying the stresses at transfer and in service.
(03 marks)

iv.) Determine the range of prestress force required at the mid span of the beam, assuming that tendons are to be placed at an eccentricity of 217 mm below neutral axis.
(08 marks)

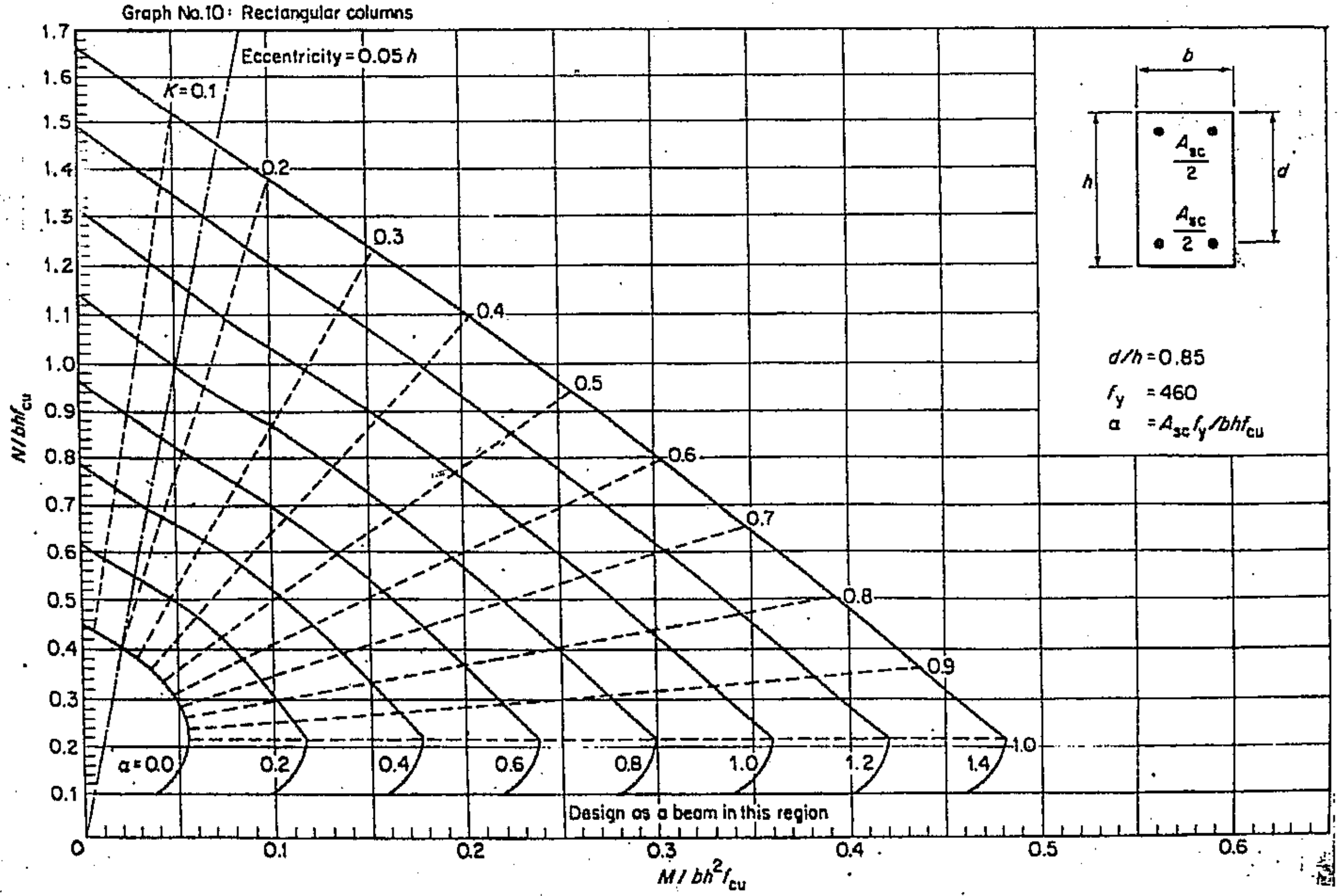
v.) Suggest the minimum possible number of tendons (and corresponding initial prestress force) and sketch a suitable physical arrangement for them (Assume $f_{pi} = 0.7 f_{pu}$).
(03 marks)

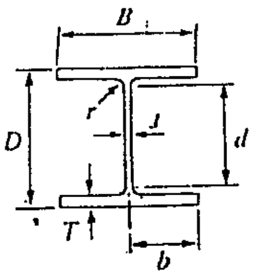
vi.) Check whether the prestress force calculated above allows for same location of tendon centroid at the supports of the beam (In other words check whether straight tendons could be used without de-bonding). If de-bonding has to be carried out, evaluate how many tendons should be de-bonded at the supports of the slab segments so that straight tendons could be used.
(05 marks)

Graph No.1 Singly reinforced beams



Graph No.10: Rectangular columns





UNIVERSAL COLUMNS
To BS4: Part 1

Designation: Serial Size (mm)	Designation: Mass per Metre (kg)	DIMENSIONS: Depth of Section D (mm)	DIMENSIONS: Width of Section B (mm)	DIMENSIONS: Thickness Web t (mm)	DIMENSIONS: Thickness Flange T (mm)	DIMENSIONS: Root Radius r (mm)	DIMENSIONS: Depth Between Fillets d (mm)	DIMENSIONS: Ratios for Local Buckling Flange b/T	DIMENSIONS: Ratios for Local Buckling Web d/t	PROPERTIES: Second Moment of Area Axis x–x (cm⁴)	PROPERTIES: Second Moment of Area Axis y–y (cm⁴)	PROPERTIES: Radius of Gyration Axis x–x (cm)	PROPERTIES: Radius of Gyration Axis y–y (cm)	PROPERTIES: Elastic Modulus Axis x–x (cm³)	PROPERTIES: Elastic Modulus Axis y–y (cm³)	PROPERTIES: Plastic Modulus Axis x–x (cm³)	PROPERTIES: Plastic Modulus Axis y–y (cm³)	PROPERTIES: Buckling Parameter u	PROPERTIES: Torsional Index x	PROPERTIES: Warping Constant H (dm⁶)	PROPERTIES: Torsional Constant J (cm⁴)	PROPERTIES: Area of Section A (cm²)
356 × 406	634	474.7	424.1	47.6	77.0	15.2	290.2	2.75	6.10	275 000	98 200	18.5	11.0	11 600	4630	14 200	7110	0.843	5.46	38.8	13 700	808
	551	455.7	418.5	42.0	67.5	15.2	290.2	3.10	6.91	227 000	82 700	18.0	10.9	9960	3950	12 100	6060	0.841	6.05	31.1	9240	702
	467	436.6	412.4	35.9	58.0	15.2	290.2	3.56	8.08	183 000	67 900	17.5	10.7	8390	3290	10 000	5040	0.839	6.86	24.3	5820	595
	393	419.1	407.0	30.6	49.2	15.2	290.2	4.14	9.48	147 000	55 400	17.1	10.5	7000	2720	8230	4160	0.837	7.86	19.0	3550	501
	340	406.4	403.0	26.5	42.9	15.2	290.2	4.70	11.0	122 000	46 800	16.8	10.4	6030	2320	6990	3540	0.836	8.85	15.5	2340	433
	287	393.7	399.0	22.6	36.5	15.2	290.2	5.47	12.8	100 000	38 700	16.5	10.3	5080	1940	5820	2950	0.835	10.2	12.3	1440	366
	235	381.0	395.0	18.5	30.2	15.2	290.2	6.54	15.7	79 100	31 000	16.2	10.2	4150	1570	4690	2380	0.834	12.1	9.54	812	300
COLCORE	477	427.0	424.4	48.0	53.2	15.2	290.2	3.99	6.05	172 000	68 100	16.8	10.6	8080	3210	9700	4980	0.815	6.91	23.8	5700	607
356 × 368	202	374.7	374.4	16.8	27.0	15.2	290.2	6.93	17.3	66 300	23 600	16.0	9.57	3540	1260	3980	1920	0.844	13.3	7.14	560	258
	177	368.3	372.1	14.5	23.8	15.2	290.2	7.82	20.0	57 200	20 500	15.9	9.52	3100	1100	3460	1670	0.844	15.0	6.07	383	226
	153	362.0	370.2	12.6	20.7	15.2	290.2	8.94	23.0	48 500	17 500	15.8	9.46	2680	944	2960	1430	0.844	17.0	5.09	251	195
	129	355.6	368.3	10.7	17.5	15.2	290.2	10.5	27.1	40 200	14 600	15.6	9.39	2260	790	2480	1200	0.843	19.9	4.16	153	165
305 × 305	283	365.3	321.8	26.9	44.1	15.2	246.6	3.65	9.17	78 800	24 500	14.8	8.25	4310	1530	5100	2340	0.855	7.65	6.33	2030	360
	240	352.6	317.9	23.0	37.7	15.2	246.6	4.22	10.7	64 200	20 200	14.5	8.14	3640	1270	4250	1950	0.854	8.73	5.01	1270	306
	198	339.9	314.1	19.2	31.4	15.2	246.6	5.00	12.8	50 800	16 200	14.2	8.02	2990	1030	3440	1580	0.854	10.2	3.86	734	252
	158	327.2	310.6	15.7	25.0	15.2	246.6	6.21	15.7	38 700	12 500	13.9	7.89	2370	806	2680	1230	0.852	12.5	2.86	379	201
	137	320.5	308.7	13.8	21.7	15.2	246.6	7.11	17.9	32 800	10 700	13.7	7.82	2050	691	2300	1050	0.851	14.1	2.38	250	175
	118	314.5	306.8	11.9	18.7	15.2	246.6	8.20	20.7	27 600	9010	13.6	7.75	1760	587	1950	892	0.851	16.2	1.97	160	150
	97	307.8	304.8	9.9	15.4	15.2	246.6	9.90	24.9	22 200	7270	13.4	7.68	1440	477	1590	723	0.85	19.3	1.55	91.1	123
254 × 254	167	289.1	264.5	19.2	31.7	12.7	200.3	4.17	10.4	29 900	9800	11.9	6.79	2070	741	2420	1130	0.852	8.49	1.62	625	212
	132	276.4	261.0	15.6	25.3	12.7	200.3	5.16	12.8	22 600	7520	11.6	6.67	1630	576	1870	879	0.85	10.3	1.18	322	169
	107	266.7	258.3	13.0	20.5	12.7	200.3	6.30	15.4	17 500	5900	11.3	6.57	1310	457	1490	695	0.848	12.4	0.894	173	137
	89	260.4	255.9	10.5	17.3	12.7	200.3	7.40	19.1	14 300	4850	11.2	6.52	1100	379	1230	575	0.849	14.4	0.716	104	114
	73	254.0	254.0	8.6	14.2	12.7	200.3	8.94	23.3	11 400	3870	11.1	6.46	894	305	989	462	0.849	17.3	0.557	57.3	92.9
203 × 203	86	222.3	208.8	13.0	20.5	10.2	160.9	5.09	12.4	9460	3120	9.27	5.32	851	299	979	456	0.85	10.2	0.317	138	110
	71	215.9	206.2	10.3	17.3	10.2	160.9	5.96	15.6	7650	2540	9.16	5.28	708	246	802	374	0.852	11.9	0.25	81.5	91.1
	60	209.6	205.2	9.3	14.2	10.2	160.9	7.23	17.3	6090	2040	8.96	5.19	581	199	652	303	0.847	14.1	0.195	46.6	75.8
	52	206.2	203.9	8.0	12.5	10.2	160.9	8.16	20.1	5260	1770	8.90	5.16	510	174	568	264	0.848	15.8	0.166	32.0	66.4
	46	203.2	203.2	7.3	11.0	10.2	160.9	9.24	22.0	4560	1540	8.81	5.11	449	151	497	230	0.846	17.7	0.142	22.2	58.8
152 × 152	37	161.8	154.4	8.1	11.5	7.6	123.5	6.71	15.2	2220	709	6.84	3.87	274	91.8	310	140	0.848	13.3	0.04	19.5	47.4
	30	157.5	152.9	6.6	9.4	7.6	123.5	8.13	18.7	1740	558	6.75	3.82	221	73.1	247	111	0.848	16.0	0.0306	10.5	38.2
	23	152.4	152.4	6.1	6.8	7.6	123.5	11.2	20.2	1260	403	6.51	3.68	166	52.9	184	80.9	0.837	20.4	0.0214	4.87	29.8