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Factors affecting the fire resistance of circular hollow steel columns filled with bar-reinforced concrete

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Factors Affecting the Fire Resistance of Circular Hollow Steel Columns Filled With Bar-Reinforced Concrete

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by T.T. Lie and E.M.A. Denham

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FACTORS AFFECTING THE FIRE RESISTANCE OF CIRCULAR HOLLOW STEEL COLUMNS FILLED WITH BAR-REINFORCED CONCRETE

ABSTRACT

Experimental and theoretical studies have been carried out to predict the fire resistance of hollow steel sections filled with various concretes. This report deals with circular steel columns filled with bar-reinforced concrete. Using a computer program, the influence of the various study variables on the fire resistance of these columns, namely, column section size, steel wall thickness, load, effective length of the column, percentage steel reinforcement, concrete cover thickness to reinforcing steel, concrete strength and type of aggregate, were investigated. The results are described and the influence of the various study variables is discussed.

FACTORS AFFECTING THE FIRE RESISTANCE OF CIRCULAR HOLLOW STEEL COLUMNS FILLED WITH BAR-REINFORCED CONCRETE

1 INTRODUCTION

For a number of years, the National Research Council of Canada (NRC) has carried out research on the fire resistance of concrete-filled steel columns. Both experimental and theoretical studies to develop methods for the prediction of the fire resistance of these columns were conducted.

Mathematical models were developed for the calculation of the fire resistance of hollow structural steel sections (HSS) filled with concrete. Columns of various steel sizes and shapes filled with various concretes were studied and a large number of tests for the validation of the models were carried out.

At present, the research has reached a stage at which sufficient data, suitable for release, have been produced. This report contains the data showing the influence of the important factors on the fire resistance of circular steel columns filled with bar-reinforced concrete. The data, generated by a mathematical model [1] programmed for computer processing, will enable the assessment of the fire resistance of the columns as a function of the variables that determine it.

The model was developed at the National Fire Laboratory of the Institute for Research in Construction, NRC, with the support of the Canadian Steel Construction Council and the American Iron and Steel Institute.

2 STUDY VARIABLES

The study variables that were considered in this report are given below.

2.1 Outside Diameter of the Steel Section

All diameters, listed in the CISC Handbook of Steel Construction [2], that were equal to or greater than 168.3 mm were considered. The diameter of 168.3 was regarded as the minimum diameter of a column still suitable for concrete filling. The selected diameters, in total six, are shown in Table 1.

2.2 Thickness of the Steel Wall

To assess the effect of the steel wall thickness on the fire resistance of the columns, the extreme values of wall thicknesses for each diameter equal to or greater than 168.3 mm (listed in the Handbook of Steel Construction) were selected for further study. The selected wall thicknesses are given in Table 1.

2.3 Load

The influence of the load on the fire resistance of the column is evaluated by calculating the strength of the column; i.e., the maximum load that the column can support, as a function of time during the exposure to fire. Because, by definition, the fire resistance of the column is equal to the time during which the column can support a specific load, the fire resistance can be determined for any load using the strength versus time relations. In this study, the strength of the column was calculated for every 10 minutes during the exposure to fire.

2.4 Effective Length

To study the influence of the effective length of the column on its fire resistance, calculations of the strength of the column, during the exposure to fire, were made for the column effective lengths of 2.5, 3.0 and 4.5 m.

2.5 Percentage Steel Reinforcement

To study the influence of the quantity of reinforcing steel, three steel percentages were selected for each steel section considered in this study. These percentages were obtained by dividing the areas of the cross sections of all reinforcing bars by the area of the cross section of the concrete core, which includes the area of the steel bar cross sections. The sizes of the steel bars considered were 11.3 mm, 16.0 mm, 19.5 mm and 25.2 mm. The sizes of the bars and the number of bars, with a minimum of four bars, were selected in such a way that the three steel percentages examined in this study approach as closely as possible to 1.5%, 3.0% and 6.0% respectively. The actual steel percentages examined are given in Table 1.

2.6 Concrete Cover to Steel

The influence of the concrete cover on the fire resistance of the column was studied for two concrete cover thicknesses, namely, 20 mm and 50 mm. The cover thickness is defined as the shortest distance between the surface of the bar reinforcement and the inner surface of the tubular steel.

2.7 Concrete Strength

The influence of the strength of the concrete filling on the fire resistance of the column was studied for concrete compressive strengths of 20, 35 and 55 MPa.

2.8 Type of Aggregate

Two concrete types, made with different aggregates, were considered in this study, namely, siliceous and carbonate. The influence of the type of aggregate was evaluated by

using, in the mathematical model, the relevant material properties of the two types of concretes. These properties are given in Reference 3 and in the Appendix.

3 CALCULATION METHOD

The calculation of the fire resistance of the columns was carried out according to the method described in Reference 1. In this method, the calculation of fire resistance is performed in three steps:

1. Calculation of the fire temperature.
2. Calculation of the temperatures in the column.
3. Calculation of the strength of the column during exposure to fire, including an analysis of stress and strain distribution.

A flow chart of the calculation procedure is shown in Figure 1.

3.1 Fire Temperature

It is assumed that the entire surface area of the column is exposed to the heat of a fire, whose temperature course follows that of the standard fire described in ASTM E119 [4] or CAN4-S101 [5]. This temperature course can be approximately described by the following expression:

$$T_f = 20 + 750 \left[1 - \text{Exp}(-3.79553\sqrt{\tau}) \right] + 170.41\sqrt{\tau}$$

where τ is the time in hours and T_f is the fire temperature in $^{\circ}\text{C}$ at the time τ .

3.2 Temperatures of Column During Fire Exposure

The column temperatures are calculated by a finite difference method. Because the finite difference heat transfer equations for the column are given in detail in Reference 1, only a description of the method will be given in this report.

In this method, the cross-sectional area of the column is subdivided into a number of concentric layers in both the steel and concrete. The temperature rise in a layer can be derived by creating a heat balance for each layer. By solving the heat balance equation for each layer, the temperature history of the column can be calculated, using the temperature dependent thermal properties of the concretes and steel of which the column is composed. These properties are given in Reference 3 and in the Appendix.

The effect of moisture in the concrete on the column temperatures is taken into account by assuming that, in each layer, the moisture starts to evaporate when the temperature reaches $100 ^{\circ}\text{C}$. In the period of evaporation, all the heat supplied to a layer is used for evaporation until the layer is dry.

3.3 Strength of Column During Fire Exposure

In order to calculate the strains and stresses in the column and its strength, the cross-sectional area of the column is divided into a number of annular elements. The temperatures, stresses and strains at the center of each element are representative of those of the entire element.

The strain in an element of steel can be given as the sum of the thermal expansion of the steel, the axial strain of the column due to compression and the strain due to bending of the column. A similar calculation is performed for the concrete elements.

To simplify the strength calculations, the following assumptions are made:

1. The curvature of the column varies from pin-ends to midheight according to a straight line relation.
2. Concrete has no tensile strength.
3. There is no slip between steel and concrete.
4. There is no composite action between the steel and concrete.

With these assumptions, and the aid of the stress-strain relations given in the Appendix, the stresses at mid-section in the steel and concrete can be calculated for any value of axial strain and curvature. From these stresses, the load that each element carries and its contribution to the internal moment at mid-section can be derived. By adding the loads and moments, the load that the column carries and the internal moment at mid-section can be calculated.

The strength of the column, during exposure to fire, can be determined by successive iterations of the axial strain and curvature until the internal moment at mid-section is in equilibrium with the applied moment.

The fire resistance of the column is derived by calculating the strength of the column as a function of the time of exposure to fire. This strength reduces gradually with time. At a certain point, the strength becomes so low that it is no longer sufficient to support the load. At this point, the column becomes unstable and is assumed to have failed. The time to reach this failure point is the fire resistance of the column.

4 RESULTS AND DISCUSSION

Using the mathematical model, described in Reference 1, and the material properties, given in the Appendix, the strength of the columns during exposure to fire was calculated for the values of the study variables mentioned in Section 2. The results are given in Tables 1-36.

The influence of the various study variables can be assessed by comparing the fire resistances calculated for the various conditions studied, with that of a reference column. For this purpose, a column with an intermediate diameter of 273 mm, a steel wall thickness of 6.4 mm, and effective length of 2.5 m, a steel percentage of approximately 1.5%, concrete cover of 20 mm, and siliceous concrete filling with a strength of 35 MPa was selected as a reference column. Two reference loads were selected for the fire resistance comparisons, namely 1400 kN which corresponds to a fire resistance of the reference column of approximately 60 min and 400 kN which corresponds to a fire resistance of 120 min for the same column.

The influence of the various study variables is shown in Figures 2-10 and will be discussed below.

4.1 Outside Diameter of the Steel Section

In Figure 2, the fire resistance of the columns is shown as a function of the steel outside diameter for the two selected reference loads of 400 kN and 1400 kN. The curves in this figure and the tabulated values in Table 2 for siliceous aggregate concrete filling and in Table 20 for carbonate aggregate concrete filling, indicate that the column outside diameter, which is a measure for the column section size, has a very great influence on the fire resistance of the column. The curves in Figure 2 roughly show that the fire resistance increases more than quadratically with the column outside diameter.

4.2 Thickness of the Steel Wall

The influence of the thickness of the steel wall on the fire resistance of the columns is shown in Figures 3 and 4 for the two selected loads of 400 kN and 1400 kN. It can be seen that for the smaller column diameters, the fire resistance tends to increase and for the larger sizes, to decrease with increasing wall thickness. The influence of the wall thickness is small, however, in comparison with that of the column section diameter. For practical purposes, it seems warranted to neglect the influence of thickness of the steel wall on the fire resistance of the column.

4.3 Load

In Figure 5, the fire resistance of the columns is shown as a function of the load for the reference column, the smallest column and the largest column considered in this study. For fire resistances above 45 minutes, which lie in the practical region, the fire resistance of the columns increases steeply with decreasing load. The influence of load on fire resistance is relatively higher for the larger columns. For the column with an outside diameter of 406 mm, for example, a reduction in load of about 35% from 3000 kN to 2000 kN increases the fire resistance of the column by approximately one half from two hours to three hours. For the reference column, which has a diameter of 273 mm, the load has to be reduced by about 80% to increase the fire resistance by one half from 2 hours to 3 hours.

4.4 Effective Length

In Figure 6, the fire resistance of the columns is shown as a function of the effective length of the column for the two selected reference loads of 400 kN and 1400 kN and three strengths of the concrete filling, namely, 20 MPa, 35 MPa and 55 MPa. The curves show that, in the range of effective lengths of 2.5-4.5 m, the fire resistance is approximately inversely proportional to the effective length.

The influence of the effective length is somewhat greater for low loads than for high loads. The influence of the compressive strength, however, is relatively greater for the higher loads. It can be seen in Figure 6 that, for low loads and higher values of the effective length, the influence of the compressive strength on the fire resistance of the column becomes very small.

4.5 Percentage Steel Reinforcement

The influence of the percentage of steel reinforcement on the fire resistance of the column is shown in Figure 7 for various column outside diameters. It can be seen that the influence of the steel percentage is small. In the practical region, namely, for fire resistances of 45 minutes or greater, the influence of the steel percentage is relatively greatest for the column with a diameter of 219 mm. For this column the fire resistance increases by somewhat less than 20% if the steel percentage is increased from 1.5% to 6.0%. For all other diameters, the relative influence of the steel percentage is considerably less.

Therefore, a fire resistance, calculated for the standard steel percentage, namely, for 1.5% will conservatively represent the fire resistances of similar columns, but with a higher percentage of steel reinforcement.

4.6 Concrete Cover

In Figure 8, the influence of the concrete cover on the fire resistance of the column is shown for various effective lengths of the column. For the columns with effective lengths of 2.5 and 3.0 m, the influence of the cover thickness is insignificant. For the columns with an effective length of 4.5 m, however, the influence of the concrete cover thickness is more pronounced. The difference in fire resistance between a cover thickness of 20 mm and that of 50 mm is about 50%. The greater influence of the cover thickness for the longer columns is likely due to the greater importance of the steel in resisting bending for the longer columns. The thicker the cover thickness, the slower the temperature rise of the steel and therefore the slower the loss of the strength of the reinforcing steel.

4.7 Concrete Strength

The influence of the concrete strength on the fire resistance of the column is shown in Figure 9 for the two selected reference loads of 400 kN and 1400 kN. The curves show a moderate influence of the concrete strength on the fire resistance of the column.

The influence of the compressive strength is greater for the higher loads than for the lower loads. For the lower loads, the fire resistance of the column increases by approximately 40% if the concrete strength is roughly tripled and for the higher load by about 100%.

4.8 Type of Aggregate

In Figure 10, the fire resistance of the reference column is shown as a function of the load, for a siliceous aggregate and for a carbonate aggregate concrete filling with 1.5% reinforcing steel. The curves in Figure 10 show that the fire resistance of the column filled with carbonate aggregate concrete is higher than that of the column filled with siliceous aggregate concrete. In the practical region, namely, for fire resistances above 45 minutes, the difference in fire resistance between carbonate aggregate and siliceous aggregate concrete filling varies from approximately 10% to 30%. The influence of the type of aggregate on the loads to which the column can be subjected to obtain a specific fire resistance, however, is much greater. To obtain a fire resistance of 120 minutes, for example, the load that can be applied on the reference column was 75% greater for carbonate aggregate concrete filling than for siliceous aggregate filling.

The difference in fire resistance tends to increase with lower loads or higher fire resistances. This tendency is also shown by the tabulated values in Tables 1-36 for other column section sizes, steel wall thicknesses, column effective lengths, steel percentage, cover thickness and concrete strengths.

Summary

In summary, it was found that of the various variables studied, the column section size and the load on the column have the greatest influence on the fire resistance of the column. The effective length of the column, concrete strength, type of aggregate and, for the longer columns, the concrete cover to steel have a moderate influence on the fire resistance of the column.

The influence of the percentage of steel reinforcement is small. The influence of the concrete cover to the steel for the shorter columns as well as that of the thickness of the steel wall is insignificant.

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NOMENCLATURE

NOTATIONS

c	specific heat [J/kg°C]
f	stress [MPa]
f'	cylinder strength of concrete at temperature T [MPa]
f'_{co}	cylinder strength of concrete at room temperature [MPa]
f_y	strength of steel at temperature T [MPa]
k	thermal conductivity [W/m°C]
K	Effective length factor
L	unsupported length of the column [m]
T	temperature [°C]

Greek Letters

α	coefficient of thermal expansion [1/°C]
ϵ	emissivity, strain [m/m]
λ	heat of vaporization [J/kg]
ρ	density [kg/m ³]
ρ_c	thermal capacity [J/m ³ °C]
τ	time [h]
ϕ	concentration of moisture in concrete by volume

Subscripts

0	at room temperature
c	of concrete
f	of fire
max	maximum
p	pertaining to proportional stress-strain relation
s	of steel
w	of water

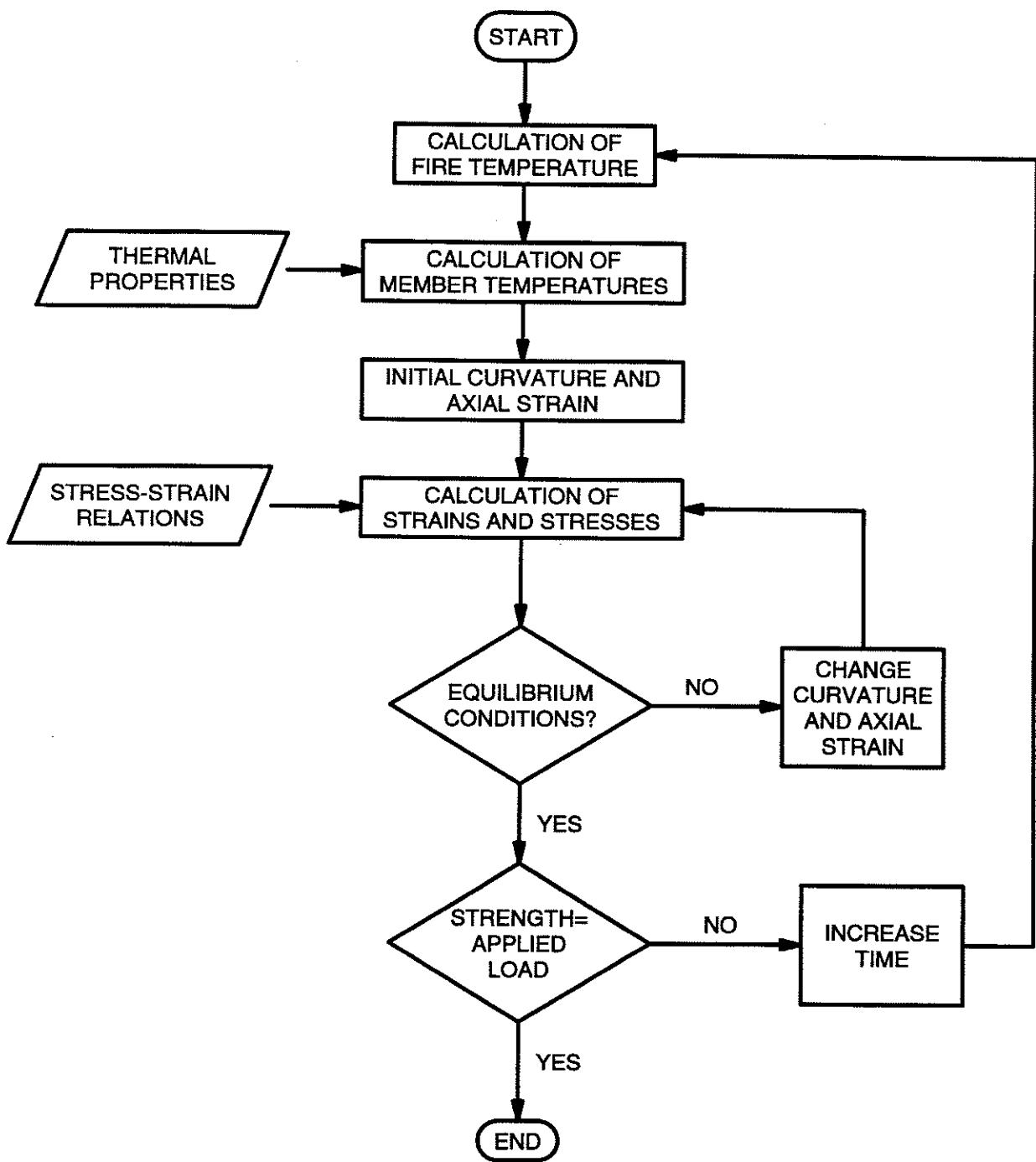


Figure 1

Flow chart of calculation procedure

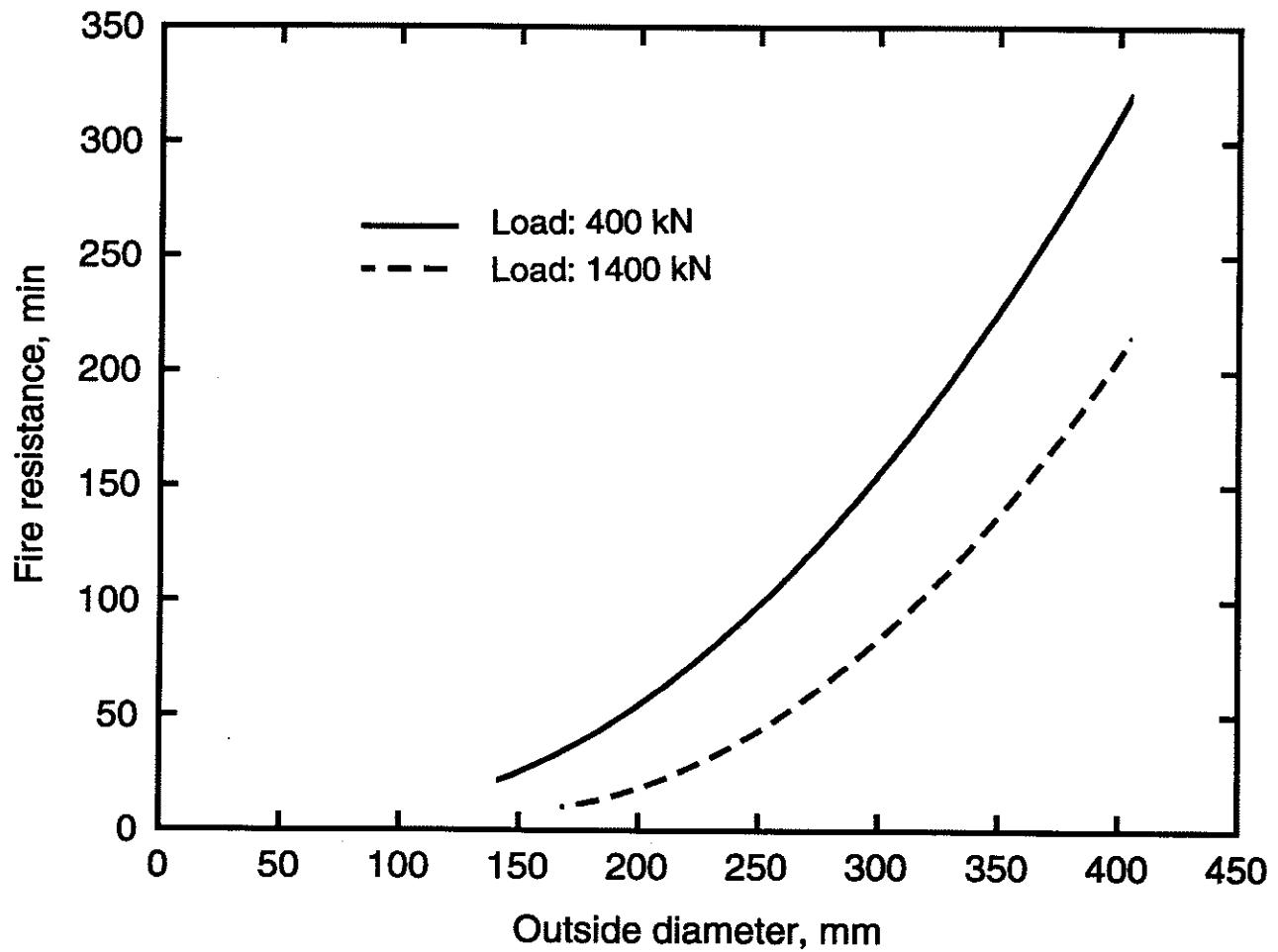


Figure 2

Fire resistance as a function of column outside diameter for loads of 400 kN and 1400 kN

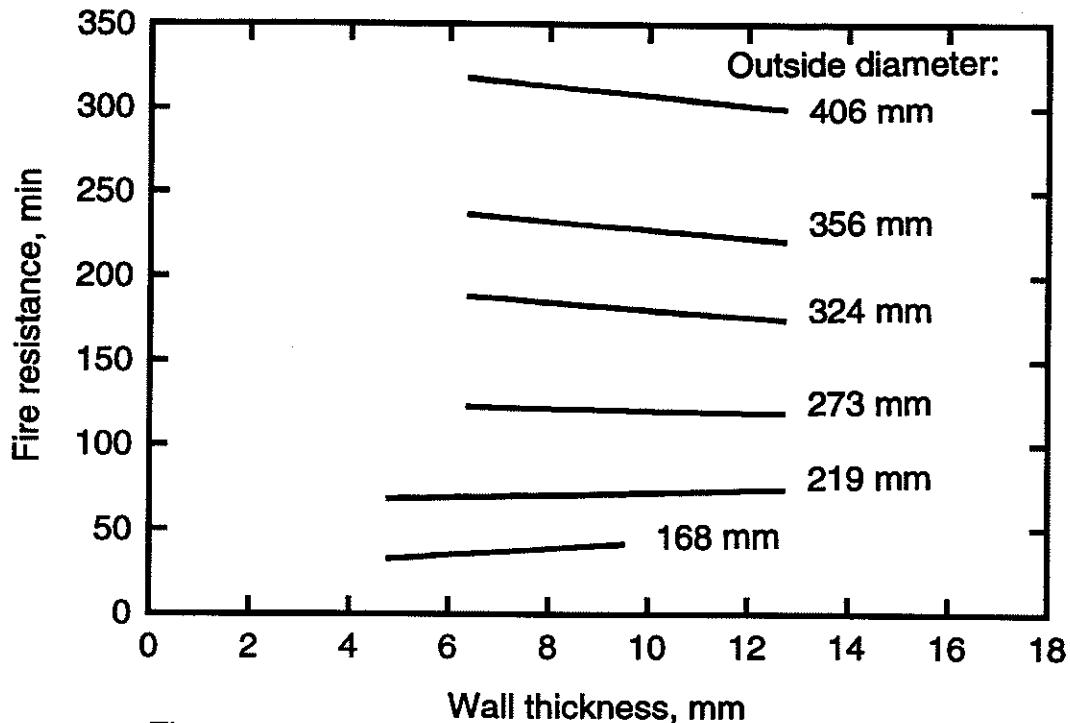


Figure 3

Fire resistance as a function of wall thickness for various column outside diameters for 1.5% reinforced siliceous concrete

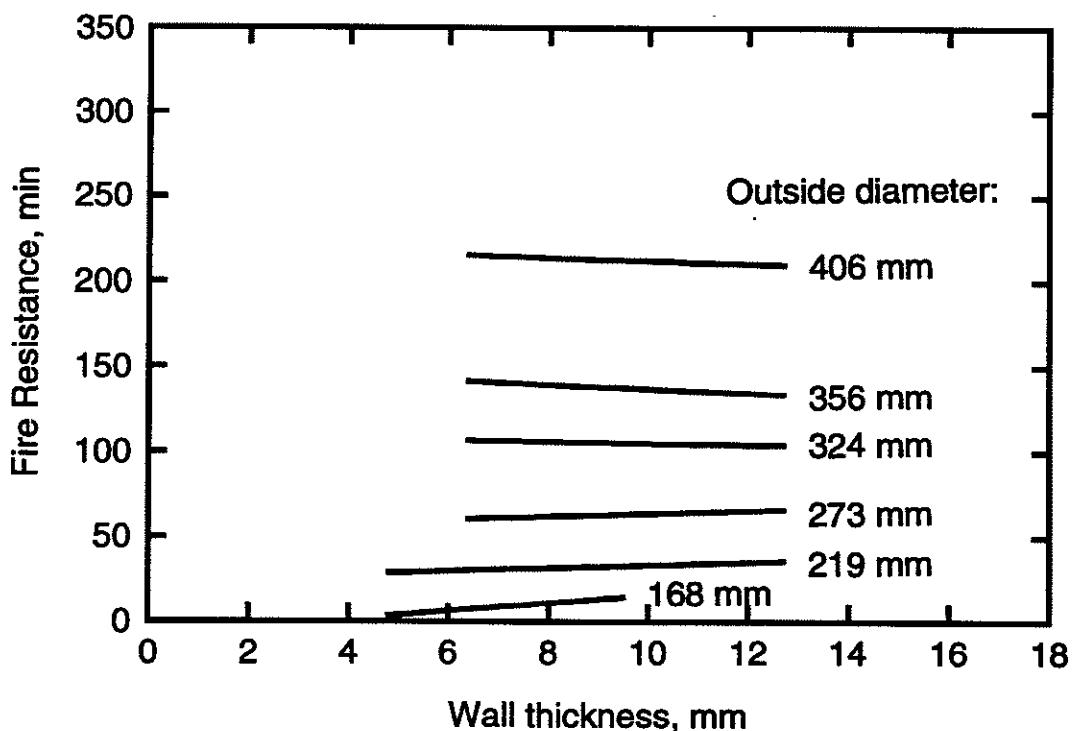


Figure 4

Fire resistance as a function of wall thickness for various column outside diameters for 3.0% reinforced siliceous concrete

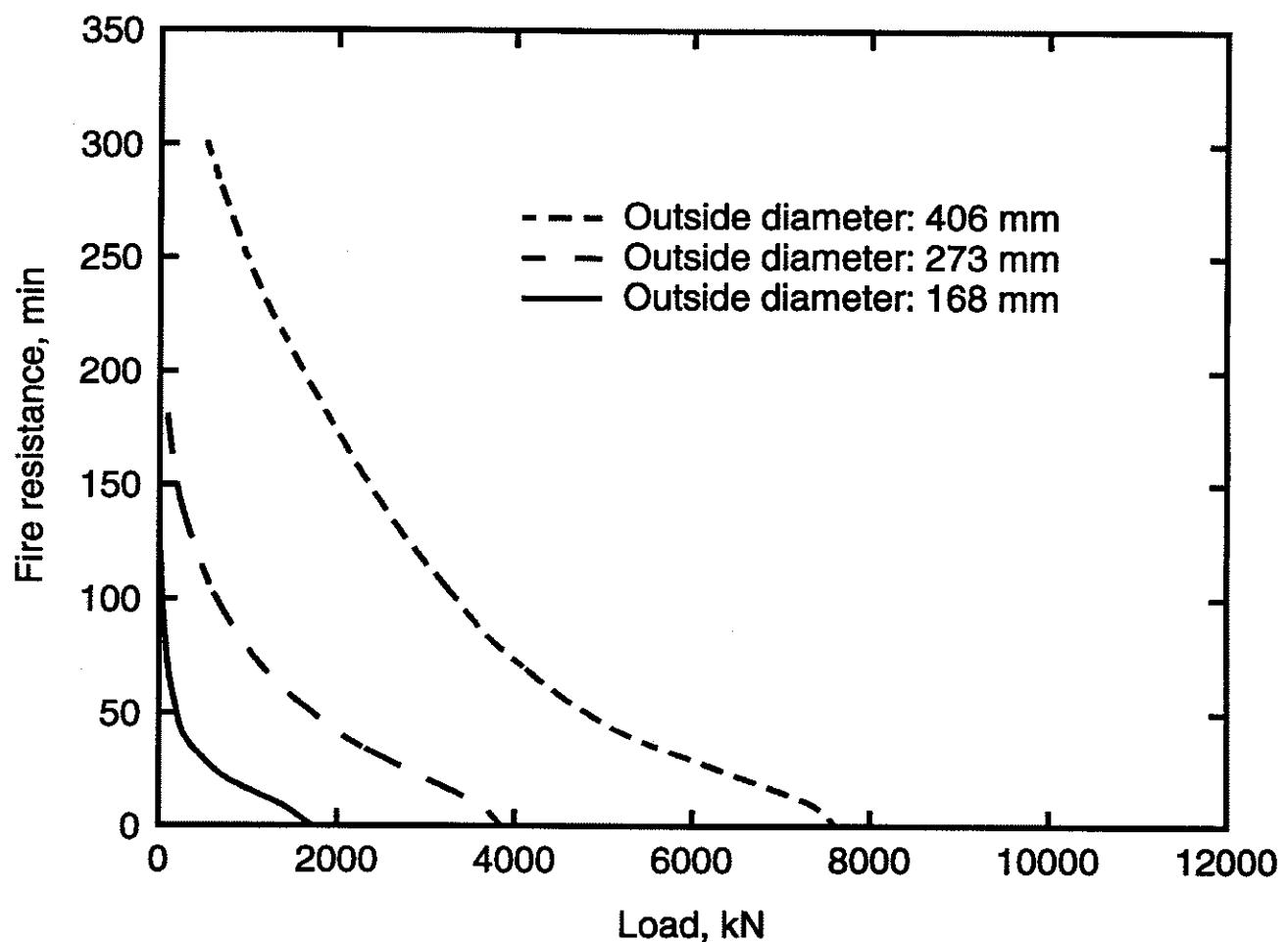


Figure 5

Fire resistance as a function of load for various column outside diameters

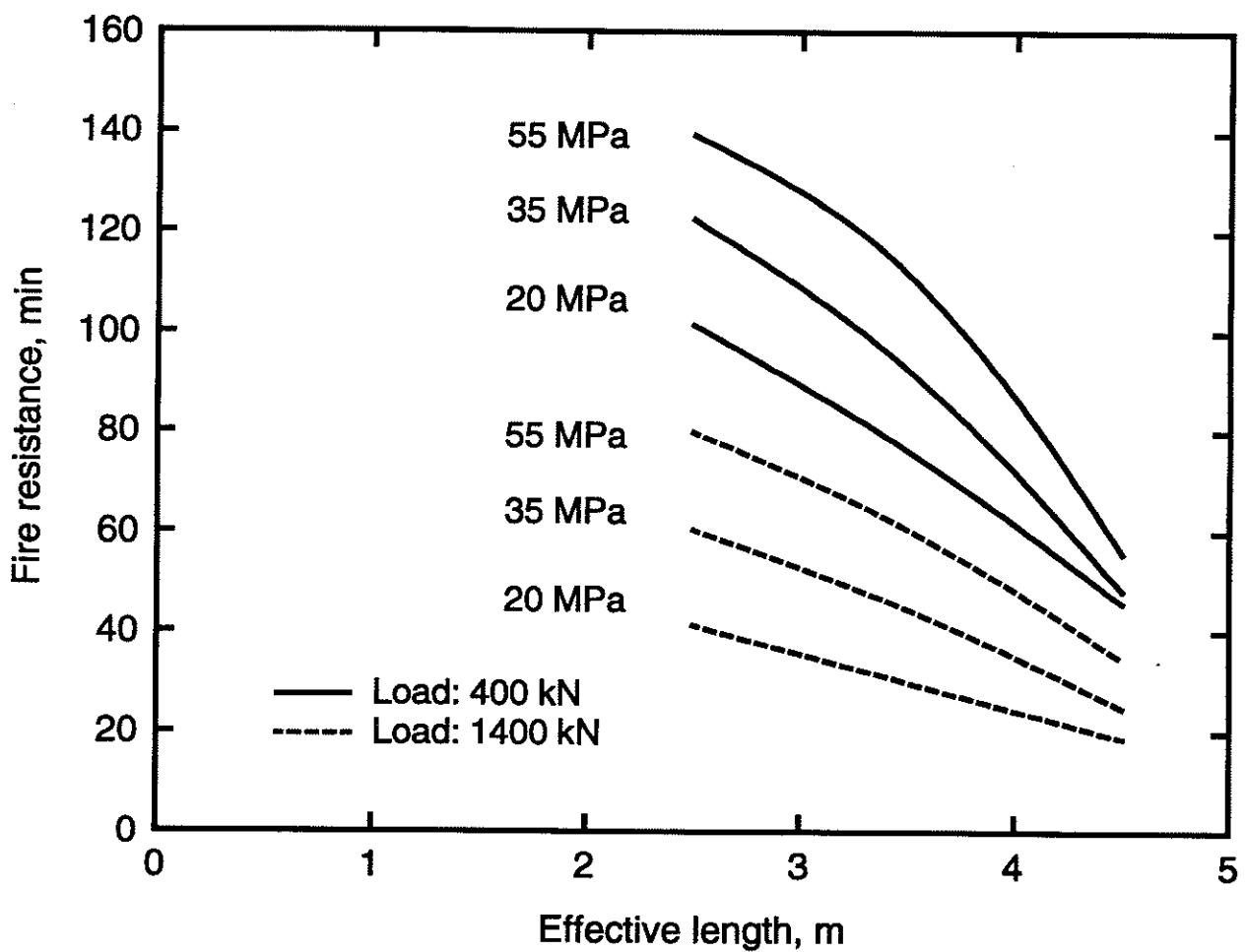


Figure 6

Fire resistance as a function of effective length of the column for loads of 400 kN and 1400 kN, and concrete strengths of 20 MPa, 35 MPa and 55 MPa

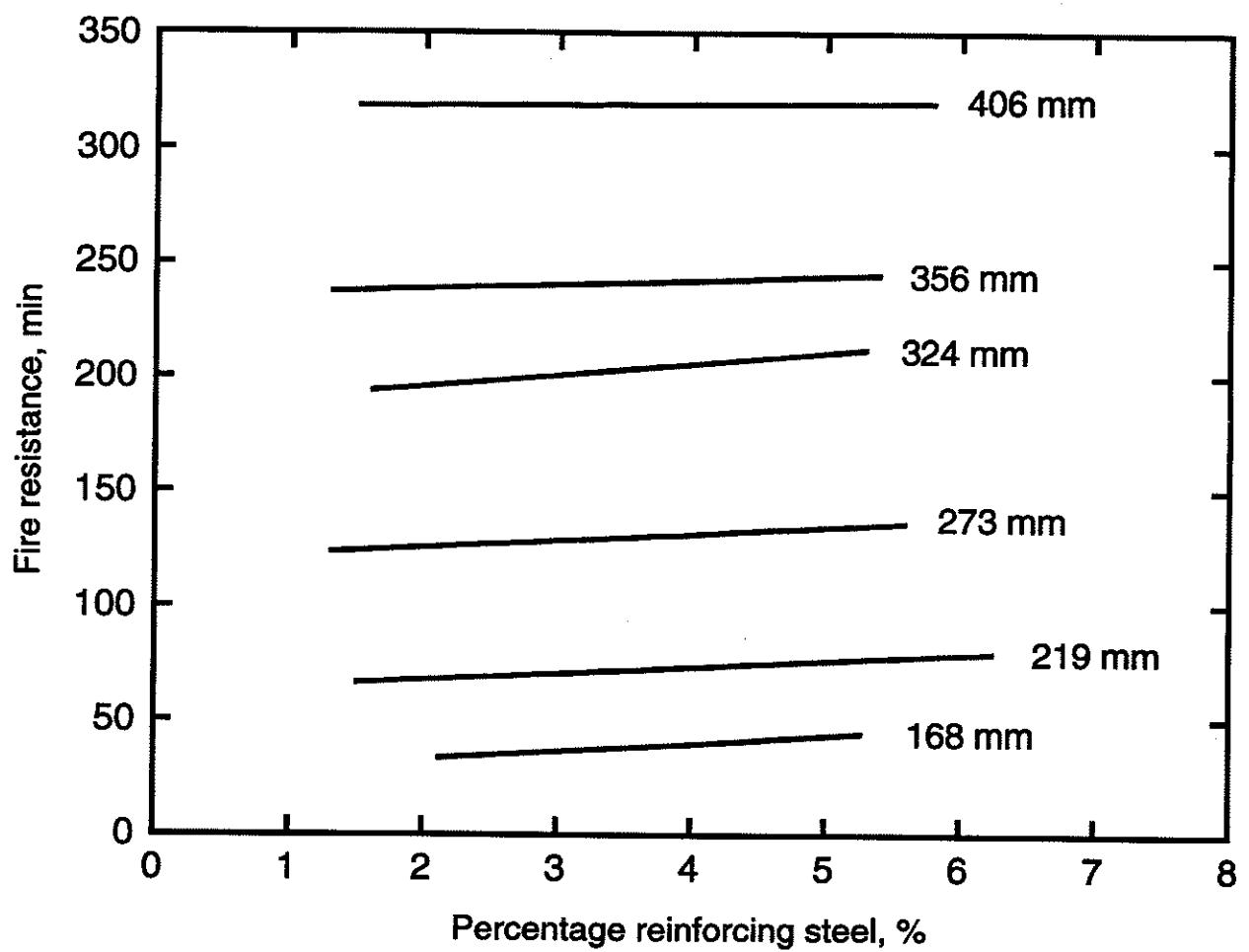


Figure 7

Fire resistance as a function of percentage reinforcing steel
for a load of 400 kN and various outside diameters

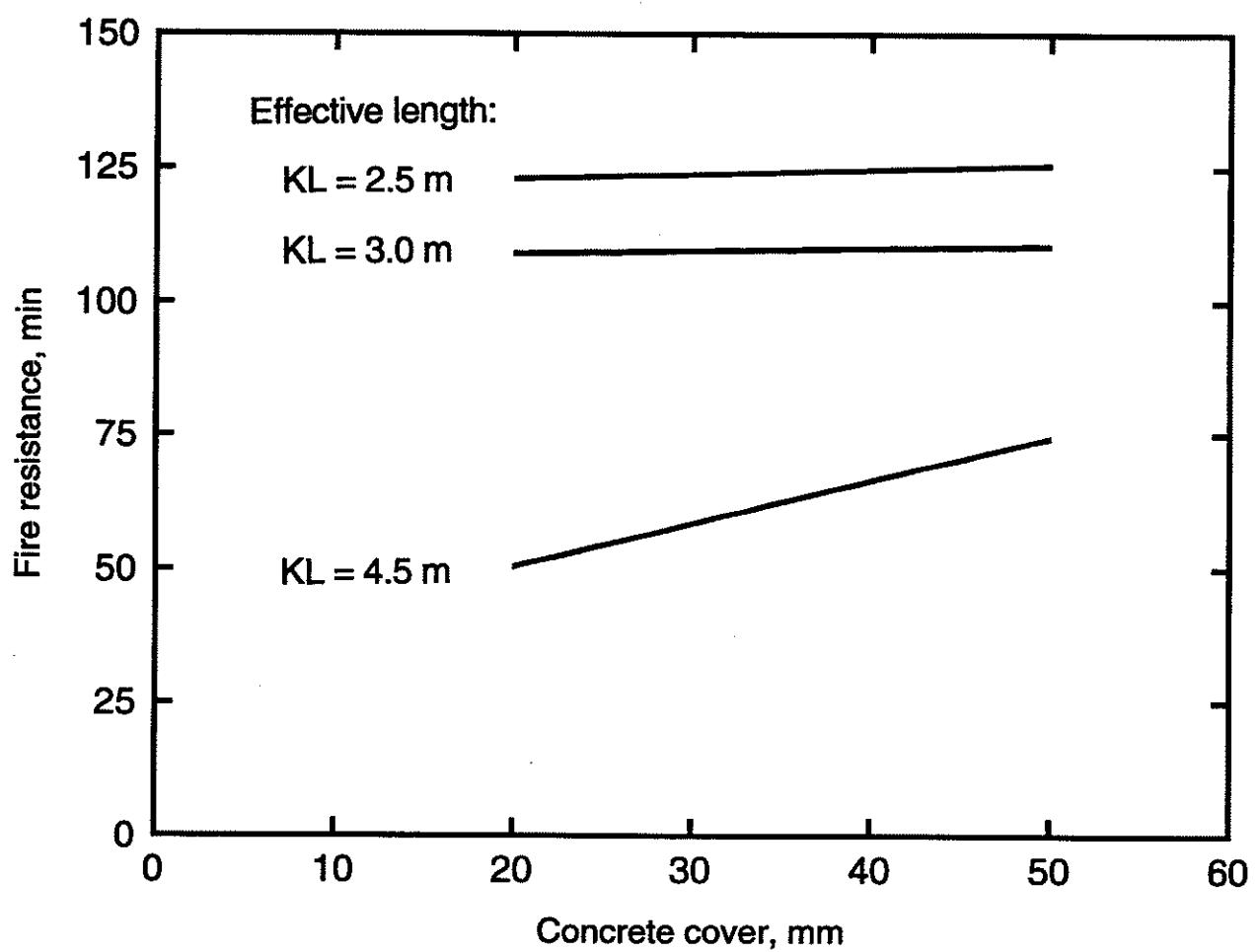


Figure 8

Fire resistance as a function of concrete cover for a load of 400 kN

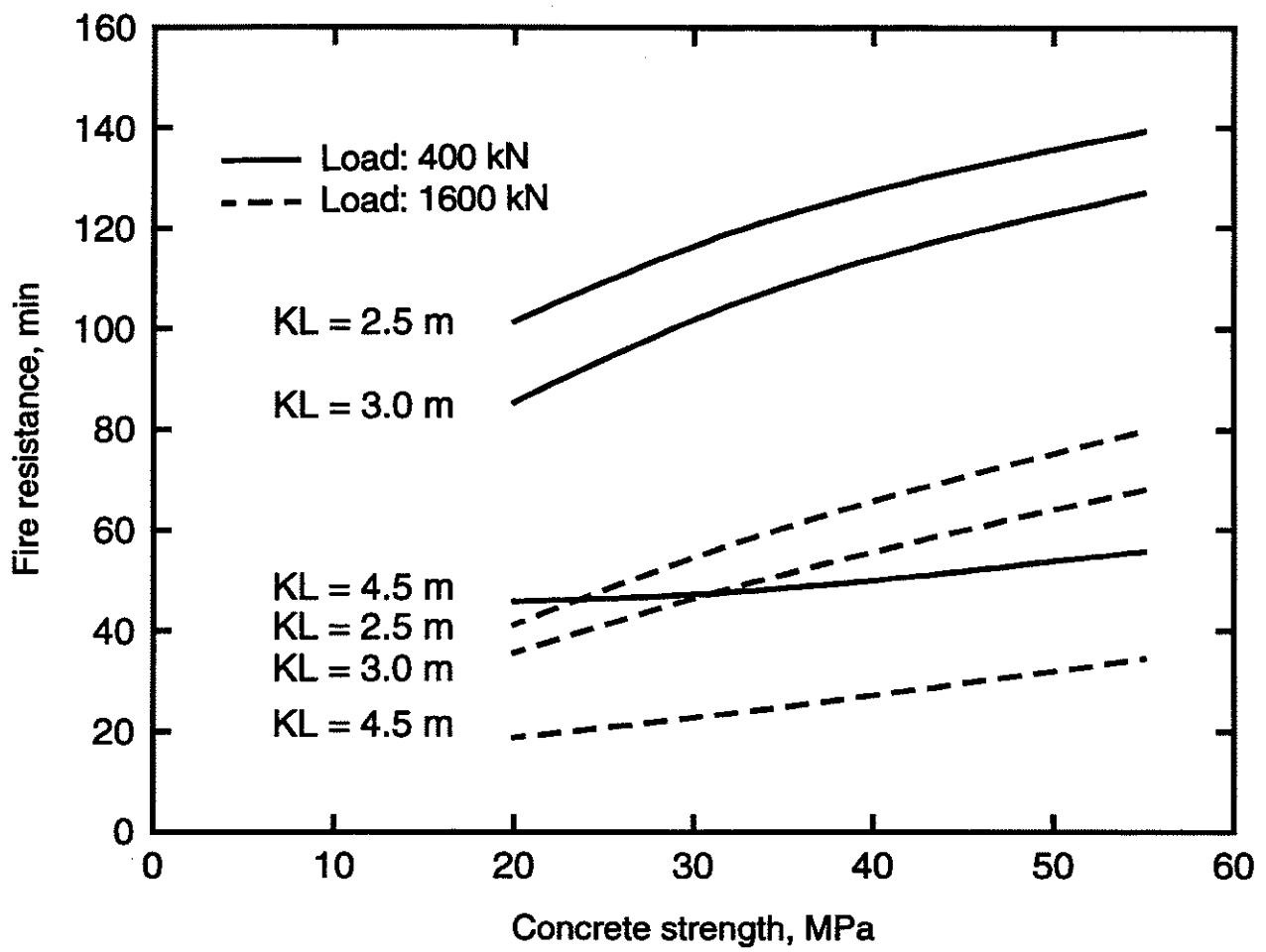


Figure 9

Fire resistance as a function of concrete strength for loads of 400 kN and 1400 kN

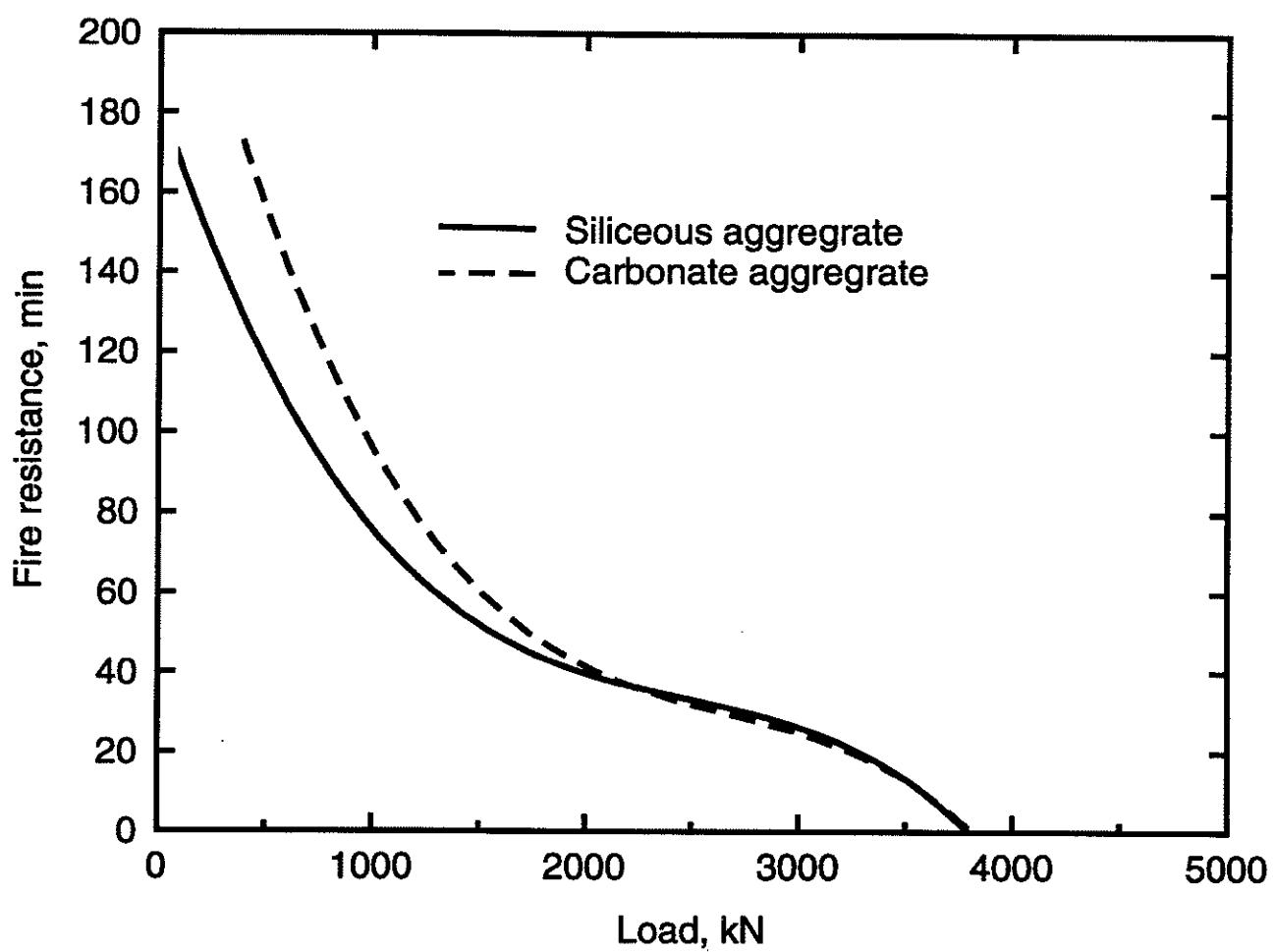


Figure 10

Fire resistance as a function of load for a 1.5% reinforced siliceous aggregate and a 1.5% reinforced carbonate aggregate concrete

**Table 1: Strength (kN) of Circular HSS Columns Filled with Bar-Reinforced Siliceous Concrete Versus Time for Various Steel Outside Diameters, Steel Wall Thicknesses and Percentage Reinforcing Steel
(Effective Length of Column: 2.5m, Concrete Strength: 20MPa, Concrete Cover: 20mm)**

Time (min)	Outside diameter (mm)						356						406																																					
	188			219			273			323			356			406																																		
	Wall Thickness (mm)	% Steel	Wall Thickness (mm)	Wall Thickness (mm)	% Steel	Wall Thickness (mm)	Wall Thickness (mm)	% Steel	Wall Thickness (mm)	Wall Thickness (mm)	% Steel	Wall Thickness (mm)	Wall Thickness (mm)	% Steel	Wall Thickness (mm)	Wall Thickness (mm)	% Steel	Wall Thickness (mm)																																
2.0	2.5	5.1	2.3	2.0	5.7	1.2	2.0	6.2	1.4	3.0	6.1	1.3	2.3	6.6	1.5	2.9	6.2	1.6	2.8	5.4	1.3	2.6	5.3	1.7	2.0	5.7	1.4	3.1	5.8	1.5	2.9	6.8	1.6	3.0	6.2															
5	1296	1586	1427	1888	1913	2075	1830	1899	2307	3345	3826	9220	3087	3344	3913	4988	4953	5519	4126	4425	6176	6141	6437	7188	4702	5251	6180	6959	7505	8410	6874	6540	7804	8465	9185	10541														
10	987	1008	1184	1602	1826	1652	1585	1784	2050	2825	3085	3407	2807	3088	3603	4284	4528	5074	3432	4138	4872	5674	5979	6707	4409	4828	5784	6474	6897	7874	6554	6193	7619	7877	8830	9870														
20	562	655	883	953	978	1065	1217	1386	1807	2186	2382	2761	2304	2552	3076	3470	3712	4237	3278	3588	4286	4787	5090	5780	3818	4507	5108	5520	6031	6838	4882	5604	6767	6877	7500	8754														
30	396	390	562	558	608	671	870	908	1147	1476	1572	2078	1830	2075	2627	2079	2896	3361	2751	3057	3707	3673	4182	4855	3254	3688	4403	4586	5007	5752	4248	4803	5835	5810	6373	7821														
40	234	283	381	385	394	449	575	655	910	1098	1073	1454	1429	1624	1988	1987	2145	2519	2245	2587	3138	3291	3959	2751	3098	3708	3724	4085	4725	3849	4131	5122	4885	5833	6413															
50	167	169	277	292	280	322	404	489	618	786	808	1091	1165	1326	1607	1624	1823	1985	1861	2245	2743	2638	2794	3288	2416	2731	3257	3105	3421	3856	3283	3685	4574	4192	4687	5478														
60	123	137	198	173	182	236	288	371	479	575	800	928	1060	1284	1147	1268	1653	1653	1690	1929	2359	2118	2364	2772	2130	2411	2885	2868	3413	2938	3323	4115	3837	4031	4839															
70	89	101	144	117	124	198	237	291	380	328	395	575	754	873	1072	985	984	1206	1458	1684	2036	1898	1901	2260	1885	2125	2511	2222	2457	2843	2881	3224	3728	3155	3481	4203														
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150	2	3	4	2	3	5	8	10	14	15	23	45	58	81	132	266	318	448	263	320	436	714	841	1032	685	807	1008	1098	1213	1391	1078	1169	1363	1600	2001	2407	1866	1998	2404											
160	1	2	3	1	2	3	5	8	10	14	15	23	45	58	81	132	266	318	448	263	320	436	714	841	1032	685	807	1008	1098	1213	1391	1078	1169	1363	1600	2001	2407	1866	1998	2404										
170	0	1	2	0	1	2	3	5	8	10	14	15	23	45	58	81	132	266	318	448	263	320	436	714	841	1032	685	807	1008	1098	1213	1391	1078	1169	1363	1600	2001	2407	1866	1998	2404									
180	0	0	1	0	1	2	3	5	8	10	14	15	23	45	58	81	132	266	318	448	263	320	436	714	841	1032	685	807	1008	1098	1213	1391	1078	1169	1363	1600	2001	2407	1866	1998	2404									
190	0	0	0	0	1	2	3	5	8	10	14	15	23	45	58	81	132	266	318	448	263	320	436	714	841	1032	685	807	1008	1098	1213	1391	1078	1169	1363	1600	2001	2407	1866	1998	2404									
200	0	0	0	0	0	1	2	3	5	8	10	14	15	23	45	58	81	132	266	318	448	263	320	436	714	841	1032	685	807	1008	1098	1213	1391	1078	1169	1363	1600	2001	2407	1866	1998	2404								
210	0	0	0	0	0	0	1	2	3	5	8	10	14	15	23	45	58	81	132	266	318	448	263	320	436	714	841	1032	685	807	1008	1098	1213	1391	1078	1169	1363	1600	2001	2407	1866	1998	2404							
220	0	0	0	0	0	0	0	1	2	3	5	8	10	14	15	23	45	58	81	132	266	318	448	263	320	436	714	841	1032	685	807	1008	1098	1213	1391	1078	1169	1363	1600	2001	2407	1866	1998	2404						
230	0	0	0	0	0	0	0	0	1	2	3	5	8	10	14	15	23	45	58	81	132	266	318	448	263	320	436	714	841	1032	685	807	1008	1098	1213	1391	1078	1169	1363	1600	2001	2407	1866	1998	2404					
240	0	0	0	0	0	0	0	0	0	1	2	3	5	8	10	14	15	23	45	58	81	132	266	318	448	263	320	436	714	841	1032	685	807	1008	1098	1213	1391	1078	1169	1363	1600	2001	2407	1866	1998	2404				
250	0	0	0	0	0	0	0	0	0	0	1	2	3	5	8	10	14	15	23	45	58	81	132	266	318	448	263	320	436	714	841	1032	685	807	1008	1098	1213	1391	1078	1169	1363	1600	2001	2407	1866	1998	2404			
260	0	0	0	0	0	0	0	0	0	0	0	1	2	3	5	8	10	14	15	23	45	58	81	132	266	318	448	263	320	436	714	841	1032	685	807	1008	1098	1213	1391	1078	1169	1363	1600	2001	2407	1866	1998	2404		
270	0	0	0	0	0	0	0	0	0	0	0	0	1	2	3	5	8	10	14	15	23	45	58	81	132	266	318	448	263	320	436	714	841	1032	685	807	1008	1098	1213	1391	1078	1169	1363	1600	2001	2407	1866	1998	2404	
280	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	3	5	8	10	14	15	23	45	58	81	132	266	318	448	263	320	436	714	841	1032	685	807	1008	1098	1213	1391	1078	1169	1363	1600	2001	2407	1866	1998	2404
290	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	3	5	8	10	14	15	23	45	58	81	132	266	318	448	263	320	436</td																	

Table 2: Strength (kN) of Circular HSS Columns Filled with Bar-Reinforced Siliceous Concrete Versus Time for Various Steel Outside Diameters, Steel Wall Thicknesses and Percentage Reinforcing Steel (Effective Length of Column: 2.5m, Concrete Strength: 35MPa, Concrete Cover: 20mm)

Table 3: Strength (kN) of Circular HSS Columns Filled with Bar-Reinforced Siliceous Concrete Versus Time for Various Steel Outside Diameters, Steel Wall Thicknesses and Percentage Reinforcing Steel
(Effective Length of Column: 2.5m, Concrete Strength: 55MPa, Concrete Cover: 20mm)

Table 4: Strength (kN) of Circular HSS Columns Filled with Bar-Reinforced Siliceous Concrete Versus Time for Various Steel Outside Diameters, Steel Wall Thicknesses and Percentage Reinforcing Steel
 (Effective Length of Column: 3.0m, Concrete Strength: 20MPa, Concrete Cover: 20mm)

**Table 5: Strength (kN) of Circular HSS Columns Filled with Bar-Reinforced Siliceous Concrete Versus Time for Various Steel Outside Diameters, Steel Wall Thicknesses and Percentage Reinforcing Steel
(Effective Length of Column: 3.0m, Concrete Strength: 35MPa, Concrete Cover: 20mm)**

Time (min)	Outside Diameter (mm)						Wall Thickness (mm)						Wall Thickness (mm)						Wall Thickness (mm)																		
	168			210			273			324			355			406			447			488															
	Wall Thickness (mm)	% Steel	Wall Thickness (mm)	% Steel	Wall Thickness (mm)	% Steel	Wall Thickness (mm)	% Steel	Wall Thickness (mm)	% Steel	Wall Thickness (mm)	% Steel	Wall Thickness (mm)	% Steel	Wall Thickness (mm)	% Steel	Wall Thickness (mm)	% Steel	Wall Thickness (mm)	% Steel	Wall Thickness (mm)	% Steel	Wall Thickness (mm)	% Steel													
4.8	2.0	2.5	5.1	2.3	2.9	6.7	1.2	2.6	5.2	1.4	3.0	6.1	1.3	2.5	5.8	1.5	2.8	6.2	1.6	2.6	5.3	1.7	2.8	5.4	1.5	2.9	5.8	1.8	3.0	6.2							
6	1418	1449	1597	2015	2046	2191	2231	2397	2606	3012	3774	4089	3748	3983	4529	5201	5445	5987	5139	5429	6147	6945	7237	7987	5851	6475	7349	8007	8525	9406	7536	8180	9498	9837	10577	11914	
10	1043	1169	1482	1507	1621	1933	2087	2345	3055	3213	3469	3420	3665	4192	4740	4982	5605	4838	5121	6224	6510	6788	7486	6187	7027	7576	8082	8904	7281	7882	8155	8476	10104	11586			
20	469	560	740	865	881	980	1448	1558	1804	2104	2387	2665	2824	3068	3568	3821	4054	4568	4212	4616	5181	5544	5902	6524	5041	5503	6291	6584	7088	7851	6572	7170	8398	8467	9004	10230	
30	247	289	446	505	525	498	1017	1188	1402	1485	1849	2286	2500	2909	2937	3165	3602	3600	3869	4504	4580	4854	6441	4412	4820	5506	5571	5689	5858	5870	8497	7512	7281	7808	8917		
40	176	203	312	318	330	331	535	634	781	935	991	1285	1788	1936	2252	2154	2232	2568	3024	3282	3670	3941	4405	3784	4132	4581	4636	4984	5541	5167	5534	6538	6296	6763	7736		
50	127	145	229	224	233	26	356	457	585	531	735	908	1435	1575	1786	1404	1607	1853	2336	2874	3119	3025	3278	3715	3371	3686	4140	3904	4184	4653	4989	5699	5940	5432	6348	6898	
60	83	103	165	141	123	172	253	330	438	472	485	774	1137	1226	1265	1194	1243	1619	2254	2469	2832	2649	2768	3121	3008	3243	3634	3406	3860	4058	4283	4544	5383	4980	5233	5658	6058
70	66	77	119	84	106	127	203	242	327	319	358	545	917	982	1064	667	843	1162	1941	2110	2424	2084	2230	2521	2847	2898	3206	2983	3085	3384	3640	4267	4925	4291	4617	5273	
80	46	54	88	70	75	83	153	201	266	230	222	419	736	773	902	496	741	824	1894	1854	2109	1720	1871	2100	2385	2549	2810	2447	2831	2907	3617	3890	4470	3798	4075	4652	
90	36	41	67	51	54	68	116	155	207	167	194	314	513	531	690	750	517	654	1584	1821	1434	1558	1750	2139	2288	2519	2141	2277	2618	3337	3591	4084	3411	3459	4139		
100	25	29	46	35	37	48	88	119	161	122	141	233	478	508	624	330	474	604	1246	1371	1554	1204	1312	1455	1869	2036	2235	1857	1984	2170	3107	3931	3787	3104	3327	3748	
114	17	20	33	21	23	32	64	80	123	73	98	170	383	411	512	269	375	490	1075	1179	1340	1006	1102	1215	1882	1781	1985	1615	1717	1887	2867	3074	3452	2816	2986	3355	
120	11	12	22	11	12	20	45	64	94	48	63	119	313	331	426	240	292	368	924	1013	1180	839	922	1026	1495	1688	1740	1395	1470	1622	2830	2790	3186	2517	2703	3036	
130	10	11	17	10	11	14	24	31	41	24	31	41	241	261	346	184	220	306	798	863	1008	703	772	868	1323	1404	1544	1195	1278	1398	2367	2856	2896	2280	2410	2707	
140	9	10	14	8	9	11	16	21	28	16	21	28	164	206	270	144	100	231	677	761	867	573	643	725	1168	1238	1382	1035	1097	1206	2232	2349	2617	2050	2167	2432	
150	8	9	11	7	8	10	14	22	26	10	17	27	142	156	226	104	77	177	571	642	745	496	527	659	1032	1097	1188	882	936	1039	2045	2181	2422	1839	1949	2180	
160	7	8	10	6	7	9	13	20	24	10	13	20	110	120	186	80	93	147	486	550	634	380	440	507	909	968	1053	768	814	861	1983	1982	2187	1871	1786	1976	
170	6	7	9	5	6	8	12	18	22	9	12	18	66	95	153	61	73	118	413	457	547	321	571	411	809	923	923	713	780	1729	1822	2017	1527	1698	1788		
180	5	6	8	4	5	7	11	16	20	8	11	16	65	71	134	44	56	94	340	385	458	282	303	331	703	745	816	575	610	673	1563	1693	1777	1856	1931	1943	1633
190	4	5	7	3	4	6	9	14	18	7	10	14	64	76	134	44	56	94	340	385	458	282	303	331	703	745	816	575	610	673	1563	1693	1777	1856	1931	1943	1633
200	3	4	6	2	3	5	8	13	17	6	9	13	61	73	134	44	56	94	340	385	458	282	303	331	703	745	816	575	610	673	1563	1693	1777	1856	1931	1943	1633
210	2	3	5	1	2	4	7	12	16	5	8	12	59	71	134	44	56	94	340	385	458	282	303	331	703	745	816	575	610	673	1563	1693	1777	1856	1931	1943	1633
220	1	2	4	0	1	3	6	11	15	4	7	11	58	69	134	44	56	94	340	385	458	282	303	331	703	745	816	575	610	673	1563	1693	1777	1856	1931	1943	1633
230	0	1	3	-	1	2	5	10	14	3	6	10	57	68	134	44	56	94	340	385	458	282	303	331	703	745	816	575	610	673	1563	1693	1777	1856	1931	1943	1633
240	-	1	2	-	0	1	4	9	13	2	5	9	56	67	134	44	56	94	340	385	458	282	303	331	703	745	816	575	610	673	1563	1693	1777	1856	1931	1943	1633
250	-	0	1	-	1	2	3	8	12	1	4	8	55	66	134	44	56	94	340	385	458	282	303	331	703	745	816	575	610	673	1563	1693	1777	1856	1931	1943	1633
260	-	0	1	-	0	1	2	7	11	0	3	7	54	65	134	44	56	94	340	385	458	282	303	331	703	745	816	575	610	673	1563	1693	1777	1856	1931	1943	1633
270	-	0	1	-	0	1	2	6	10	0	2	6	53	64	134	44	56	94	340	385	458	282	303	331	703	745	816	575	610	673	1563	1693	1777	1856	1931	1943	1633
280	-	0	1	-	0	1	2	5	9	0	1	5	52	63	134	44	56	94	340	385	458	282	303	331	703	745	816	575	610	673	1563	1693	1777	1856	1931	1943	1633
290	-	0	1	-	0	1	2	4	8	0	0	4	51	62	134	44	56	94	340	385	458	282	303	331	703	745	816	575	610	673	1563	1693	1777	1856	1931	1943	1633
300	-	0	1	-	0	1	2	3	7	0	0	3	50	61	134	44	56	94	340	385	458	282	303	331	703	745	816	575	610	673	1563	1693	1777	1856	1931	1943	1633
310	-	0	1	-	0	1	2	2	6	0	0	2	49	60	134	44	56	94	340	385	458	282	303	331	703	745	816	575	610	673	1563	1693	1777	1856	1931	1943	1633
320	-	0	1	-																																	

Table 6: Strength (kN) of Circular HSS Columns Filled with Bar-Reinforced Siliceous Concrete Versus Time for Various Steel Outside Diameters, Steel Wall Thicknesses and Percentage Reinforcing Steel
(Effective Length of Column: 3.0m, Concrete Strength: 55MPa, Concrete Cover: 20mm)

Table 7: Strength (kN) of Circular HSS Columns Filled with Bar-Reinforced Siliceous Concrete Versus Time for Various Steel Outside Diameters, Steel Wall Thicknesses and Percentage Reinforcing Steel
 (Effective Length of Column: 4.5m, Concrete Strength: 20MPa, Concrete Cover: 20mm)

Table 8: Strength (kN) of Circular HSS Columns Filled with Bar-Reinforced Siliceous Concrete Versus Time for Various Steel Outside Diameters, Steel Wall Thicknesses and Percentage Reinforcing Steel (Effective Length of Column: 4.5m, Concrete Strength: 35MPa, Concrete Cover: 20mm)

Table 9: Strength (kN) of Circular HSS Columns Filled with Bar-Reinforced Siliceous Concrete Versus Time for Various Steel Outside Diameters, Steel Wall Thicknesses and Percentage Reinforcing Steel (Effective Length of Column: 4.5m, Concrete Strength: 55MPa, Concrete Cover: 20mm)

Steel Plate Properties																																										
Thickness (mm)	Outer Diameter (mm)								Wall Thickness (mm)																																	
	210	218	226	234	273	324	355	406	4.8	5.1	5.4	5.7	6.0	6.4	6.8	7.2																										
2.0	1427	1442	1560	2030	2042	2171	2502	2849	2906	3132	3876	4127	4298	4523	5020	5643	5759	6244	6104	6372	7007	7649	7939	8615	7276	7765	8649	9038	9649	11294	11294	11582	12192	13664								
2.5	694	772	1118	1120	1157	1742	1864	2123	2722	2839	2988	3575	3880	4482	4614	4915	5275	5651	5893	6548	6842	7187	7923	8796	7253	7974	8339	8802	9557	9075	9642	10836	10970	11244	12698							
3.0	301	301	591	563	564	621	1349	1594	1581	1254	2735	3114	3831	3271	3616	4141	4908	4995	5596	6514	6859	6722	6878	6254	6918	7044	7480	8129	8207	8728	9809	9606	10106	11241	11241	11241						
3.5	154	162	196	321	296	312	398	536	754	889	940	1020	2074	2312	2688	1881	1578	3086	4080	4810	4318	4759	6295	5071	5343	5884	5801	6105	6832	7285	7689	8801	8183	8702	9802							
4.0	98	106	143	182	169	185	200	390	531	642	636	542	563	1198	1547	1191	1094	1846	3046	3246	3605	3360	3605	3983	4231	4494	4849	4674	4894	5310	6286	6821	7420	7036	7418	8151						
5.0	68	62	105	120	126	141	147	273	397	386	418	462	546	842	1161	850	884	1423	2584	2710	2926	1209	2193	2791	3408	3802	4109	3807	4201	4290	5810	5853	6606	6977	6354	6989						
6.0	40	45	76	76	79	79	106	204	296	261	290	365	286	807	859	621	706	1106	2108	2211	2068	832	1631	2114	3105	3275	3502	3224	3344	3457	5032	5275	5839	5285	5528	6046						
7.0	30	34	56	64	56	60	69	157	239	172	170	279	225	485	676	944	561	895	1863	1553	1862	686	1252	1845	2682	2795	2982	2560	2808	1934	4532	4745	5168	4860	4817	5246						
8.0	22	26	49	39	41	50	66	121	182	124	120	219	173	361	541	285	437	677	1382	1250	1383	502	1000	1332	2239	2370	2370	4204	4573	3874	4180	4520	4520	4520								
9.0	19	21	32	29	30	37	60	91	144	90	107	170	132	281	436	233	348	538	1065	858	1147	385	612	1079	1896	2020	1990	1815	1882	1390	3604	3785	4094	3481	3828	3982						
10.0	13	15	23	20	21	26	36	70	113	68	76	134	100	218	361	187	272	422	888	848	966	293	860	886	1866	1711	1598	1471	1348	1100	3301	3419	3706	3122	3237	3475						
11.0	9	10	18	13	13	18	28	54	89	45	67	104	77	188	282	147	211	331	761	715	592	486	542	740	1429	1440	1353	1219	1151	917	2956	3064	3298	2780	2839	3095						
12.0	5	6	11	6	7	10	21	40	68	28	39	77	65	153	238	112	160	255	634	632	703	496	446	620	1250	1152	1082	1056	761	2813	2727	2802	2410	2514	2800							
13.0	4	5	9	6	7	8	17	37	60	44	44	87	122	187	77	113	192	648	507	597	384	576	523	1078	1086	1005	902	884	639	2351	2420	2551	2111	2145	2244							
14.0	3	4	7	5	6	7	13	23	34	23	34	42	61	155	53	72	139	487	421	511	364	215	439	941	950	915	787	761	539	2087	2176	2289	1880	1907	2003							
15.0	2	3	5	4	5	6	10	20	21	26	36	70	113	68	76	134	100	218	361	187	272	422	888	848	966	293	860	886	1866	1711	1598	1471	1348	1100	3301	3419	3706	3122	3237	3475		
16.0	1	2	3	2	3	4	8	18	33	13	13	18	28	54	89	45	67	104	77	188	282	147	211	331	761	715	592	486	542	740	1429	1440	1353	1219	1151	917	2956	3064	3298	2780	2839	3095
17.0	0	1	2	1	2	3	7	17	33	13	13	18	28	54	89	45	67	104	77	188	282	147	211	331	761	715	592	486	542	740	1429	1440	1353	1219	1151	917	2956	3064	3298	2780	2839	3095

**Table 10: Strength (kN) of Circular HSS Columns Filled with Bar Reinforced Siliceous Concrete Versus Time for Various Steel Outside Diameters, Steel Wall Thicknesses and Percentage Reinforcing Steel
(Effective Length of Column: 2.5m, Concrete Strength: 20MPa, Concrete Cover: 50mm)**

Time (min)	168			219			273			324			356			406		
	Wall Thickness (mm)			Wall Thickness (mm)			Wall Thickness (mm)			Wall Thickness (mm)			Wall Thickness (mm)			Wall Thickness (mm)		
	% Steel	Wall Thickness (mm)	% Steel	% Steel	Wall Thickness (mm)	% Steel	% Steel	Wall Thickness (mm)	% Steel	% Steel	Wall Thickness (mm)	% Steel	% Steel	Wall Thickness (mm)	% Steel	Wall Thickness (mm)	% Steel	
2.0	2.6	5.1	2.3	2.9	6.7	1.2	2.6	5.2	1.4	3.0	6.1	1.3	2.6	6.6	1.5	2.9	6.2	
3	1220	1257	1406	1481	1916	2033	1823	1942	2228	3345	3610	3810	3050	3226	3875	4661	4895	5483
10	911	932	1013	1480	1483	1548	1579	1739	2007	3049	3287	2806	3038	3558	4284	4465	5019	5144
20	621	631	672	908	914	943	1225	1378	1638	2148	2236	2148	3062	3465	3702	4216	5219	5758
30	304	240	324	540	534	552	917	1087	1318	1448	1504	1622	1883	2108	2582	2704	3436	3748
40	189	185	238	395	388	230	682	659	1067	995	1052	1112	1489	1708	2159	2078	2303	2772
50	115	124	168	243	240	176	503	627	742	645	883	1247	1415	1807	1615	1783	2205	2352
60	79	87	118	153	156	170	367	468	682	537	527	700	904	1138	1478	1244	1747	2569
70	71	86	89	107	111	120	276	386	503	280	394	531	613	928	1222	921	1068	1350
80	52	57	67	77	80	89	204	273	400	275	303	414	669	771	1031	718	830	1097
90	38	41	52	56	57	66	154	213	323	205	238	334	549	640	866	586	681	890
100	26	29	36	38	40	46	116	167	282	151	186	266	450	620	755	450	539	795
110	17	19	26	24	25	30	86	120	96	141	209	343	440	619	953	426	403	901
120	9	11	17	12	13	16	61	97	160	64	99	154	208	362	628	276	339	497
130	6	7	11	7	11	11	11	11	11	11	11	11	11	11	11	11	11	11
140	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
150	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
160	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
170	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
180	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
190	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
200	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
210	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
220	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
230	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
240	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
250	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
260	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
270	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
280	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
290	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
300	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
310	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
320	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
330	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
340	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
350	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
360	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
370	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
380	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
390	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
400	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
410	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
420	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
430	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
440	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
450	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
460	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
470	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
480	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
490	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
500	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
510	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
520	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
530	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
540	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
550	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
560	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
570	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
580	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
590	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
600	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
610	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
620	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
630	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
640	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
650	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
660	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
670	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
680	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
690	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
700	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
710	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
720	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
730	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
740	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
750	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
760	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
770	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
780	4	4	4	4</td														

Table 11: Strength (kN) of Circular HSS Columns Filled with Bar-Reinforced Siliceous Concrete Versus Time for Various Steel Outside Diameters, Steel Wall Thicknesses and Percentage Reinforcing Steel
 (Effective Length of Column: 2.5m, Concrete Strength: 35MPa, Concrete Cover: 50mm)

Steel Plate Properties																408																															
Thickness (mm)	219				273				324				355				Wall Thickness (mm)	Wall Thickness (mm)	Wall Thickness (mm)																												
	4.8	5.1	5.4	5.7	12.7	13.0	13.3	13.6	12.7	13.0	13.3	13.6	12.7	13.0	13.3	13.6																															
1.00	1485	1517	1645	2102	2133	2245	2303	2484	2756	3743	3817	4214	3936	4050	4450	5361	5412	6154	6206	5408	6231	7098	7400	8120	8018	8649	7451	8137	8678	8583	7800	8244	8576	10468	10722	12070											
1.00	1125	1156	1222	1640	1644	1749	2057	2204	2488	3263	3426	3656	3570	3611	4332	4952	6161	5881	4951	5238	5945	6684	6974	7860	7671	7873	7331	7982	9258	8659	10248	11861	10458														
1.00	706	710	715	1014	1020	1059	1859	1811	2081	2477	2673	2723	3065	3280	3784	4142	4387	4871	4406	4878	5387	6101	6773	5175	5887	6530	6790	7298	8123	8675	8598	8544	9168	9345													
1.00	350	367	438	601	806	814	1281	1450	1673	1288	1784	1847	2682	2798	3274	3326	3553	4027	3858	4148	4822	4922	6175	5833	4803	6111	5836	5620	6321	7132	6630	6852	7933	7487	8116	9345											
1.00	242	259	312	379	583	288	978	1105	1326	1161	1198	1374	2132	2782	2815	2825	3273	3326	3613	4261	4113	4372	4881	4048	4532	4979	5457	6232	5409	6010	7258	6575	7168	8410	8410												
1.00	165	167	210	235	270	284	721	813	884	865	859	1087	1792	1941	2350	2091	2235	2845	2091	3295	3483	3610	3753	4943	3669	4114	4871	4301	4737	5434	4984	5575	6775	6775	6264	7570	6917										
1.00	161	168	142	159	172	140	529	605	743	479	647	832	1459	1588	1912	1845	1797	2105	2624	2893	3451	3053	3270	3821	3287	3750	4414	3822	4227	4887	4613	6172	6321	6229	6790	6790	6229										
1.00	70	71	79	104	116	118	123	344	453	571	362	475	611	1214	1316	1571	1277	1372	1828	2311	2553	3044	2837	2711	3200	3006	3392	4006	3280	3848	4237	4300	4836	5918	4877	5203	6236										
1.00	51	55	78	83	85	93	298	342	443	298	342	443	1000	1086	1312	1001	1081	1308	2065	2272	2721	2161	2323	2754	2747	3086	3640	2884	3196	3728	3886	4472	5470	4200	4897	5700	4897	5700									
1.00	42	45	53	58	61	68	217	281	349	200	287	368	630	903	1046	808	861	1086	1807	2001	2396	1847	1997	2376	2529	2840	3322	2568	2853	3323	3745	4206	5156	3862	4298	6231											
1.00	28	31	40	40	41	48	160	198	280	152	206	286	678	744	916	637	688	808	1584	1770	2124	1689	1717	2061	2259	2558	2986	2264	2518	2940	3628	3655	4843	3550	3881	4828											
1.00	18	19	27	24	26	31	116	118	123	344	453	571	771	506	548	709	1398	1551	1873	1361	1475	1780	2059	2303	2865	2000	2236	2568	3511	3712	4527	3276	3669	4443													
1.00	9	11	17	12	13	16	80	109	172	70	106	165	449	502	652	391	434	580	1329	1483	1157	1287	1529	1860	2089	2451	1746	1987	2278	3063	3461	4200	3002	3364	4053												
1.00	40	41	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44																
1.00	15	16	21	22	22	109	152	116	148	221	109	152	216	496	511	556	611	771	506	548	709	1398	1551	1873	1361	1475	1780	2059	2303	2865	2000	2236	2568	3511	3712	4527	3276	3669	4443								
1.00	10	11	17	12	13	16	80	109	172	70	106	165	449	502	652	391	434	580	1329	1483	1157	1287	1529	1860	2089	2451	1746	1987	2278	3063	3461	4200	3002	3364	4053												
1.00	171	206	310	121	152	238	681	818	1025	594	874	974	601	732	834	1007	698	656	855	890	1007	1029	1229	2176	2428	2836	1957	2181	2864	1987	2006	1142	1476	1887	2006	1987											
1.00	136	171	262	93	125	202	584	713	809	498	577	758	1086	1212	1430	912	1075	1290	796	927	1085	1229	1777	1758	2196	2262	2734	1816	2003	2456	1807	1931	1341	1341	1548	907	1030	1740									
1.00	104	138	219	68	98	166	491	615	794	420	494	660	957	1078	1290	796	829	447	521	658	651	734	374	213	263	374	374	583	651	829	447	521	658	651	734	374	213	263	374	374	583						
1.00	201	290	413	175	223	324	490	576	732	381	456	556	629	690	850	1144	991	798	951	1874	2076	2521	1652	1818	1107	1282	1506	1046	1226	1226	1226	1226	1226	1226	1226	1226	1226	1226									
1.00	365	406	616	304	366	501	320	384	477	421	503	643	355	484	527	266	320	406	320	384	477	1309	1683	1006	1142	1476	1887	2006	1987	1987	1987	1987	1987	1987	1987	1987	1987	1987	1987	1987							
1.00	206	404	543	264	314	438	842	787	918	420	494	660	957	1078	1290	796	829	447	521	658	651	734	374	213	263	374	374	583	651	829	447	521	658	651	734	374	213	263	374	374	583						
1.00	246	347	476	213	263	374	535	705	829	420	494	660	957	1078	1290	796	829	447	521	658	651	734	374	213	263	374	374	583	651	829	447	521	658	651	734	374	213	263	374	374	583						
1.00	201	290	413	175	223	324	490	576	732	381	456	556	629	690	850	1144	991	798	951	1874	2076	2521	1652	1818	1107	1282	1506	1046	1226	1226	1226	1226	1226	1226	1226	1226	1226	1226	1226								
1.00	365	406	616	304	366	501	320	384	477	421	503	643	355	484	527	266	320	406	320	384	477	1309	1683	1006	1142	1476	1887	2006	1987	1987	1987	1987	1987	1987	1987	1987	1987	1987	1987	1987	1987	1987	1987	1987	1987	1987	1987
1.00	215	277	374	154	206	301	438	582	734	420	494	660	957	1078	1290	796	829	447	521	658	651	734	374	213	263	374	374	583	651	829	447	521	658	651	734	374	213	263	374	374	583						
1.00	190	298	324	122	158	244	438	582	734	420	494	660	957	1078	1290	796	829	447	521	658	651	734	374	213	263	374	374	583	651	829	447	521	658	651	734	374	213	263	374	374	583						
1.00	149	198	277	99	125	203	438	582	734	420	494	660	957	1078	1290	796	829	447	521	658	651	734	374	213	263	374	374	583	651	829	447	521	658	651	734	374	213	263	374	374	583						

Table 12: Strength (kN) of Circular HSS Columns Filled with Bar-Reinforced Siliceous Concrete Versus Time for Various Steel Outside Diameters, Steel Wall Thicknesses and Percentage Reinforcing Steel
 (Effective Length of Column: 2.5m, Concrete Strength: 55MPa, Concrete Cover: 50mm)

Table 13: Strength (kN) of Circular HSS Columns Filled with Bar-Reinforced Siliceous Concrete Versus Time for Various Steel Outside Diameters, Steel Wall Thicknesses and Percentage Reinforcing Steel
(Effective Length of Column: 3.0m, Concrete Strength: 20MPa, Concrete Cover: 50mm)

Table 14: Strength (kN) of Circular HSS Columns Filled with Bar-Reinforced Siliceous Concrete Versus Time for Various Steel Outside Diameters, Steel Wall Thicknesses and Percentage Reinforcing Steel
 (Effective Length of Column: 3.0m, Concrete Strength: 35MPa, Concrete Cover: 50mm)

Table 15: Strength (kN) of Circular HSS Columns Filled with Bar-Reinforced Siliceous Concrete Versus Time for Various Steel Outside Diameters, Steel Wall Thicknesses and Percentage Reinforcing Steel
 (Effective Length of Column: 3.0m, Concrete Strength: 55MPa, Concrete Cover: 50mm)

Table 16: Strength (kN) of Circular HSS Columns Filled with Bar-Reinforced Siliceous Concrete Versus Time for Various Steel Outside Diameters, Steel Wall Thicknesses and Percentage Reinforcing Steel
 (Effective Length of Column: 4.5m, Concrete Strength: 20MPa, Concrete Cover: 50mm)

Table 17: Strength (kN) of Circular HSS Columns Filled with Bar-Reinforced Siliceous Concrete Versus Time for Various Steel Outside Diameters, Steel Wall Thicknesses and Percentage Reinforcing Steel
 (Effective Length of Column: 4.5m, Concrete Strength: 35MPa, Concrete Cover: 50mm)

Table 18: Strength (kN) of Circular HSS Columns Filled with Bar-Reinforced Siliceous Concrete Versus Time for Various Steel Outside Diameters, Steel Wall Thicknesses and Percentage Reinforcing Steel
(Effective Length of Column: 4.5m, Concrete Strength: 55MPa, Concrete Cover: 50mm)

Table 19: Strength (kN) of Circular HSS Columns Filled with Bar-Reinforced Carbonate Concrete Versus Time for Various Steel Outside Diameters, Steel Wall Thicknesses and Percentage Reinforcing Steel
 (Effective Length of Column: 2.5m, Concrete Strength: 20MPa, Concrete Cover: 20mm)

Table 20: Strength (kN) of Circular HSS Columns Filled with Bar-Reinforced Carbonate Concrete Versus Time for Various Steel Outside Diameters, Steel Wall Thicknesses and Percentage Reinforcing Steel
 (Effective Length of Column: 2.5m, Concrete Strength: 35MPa, Concrete Cover: 20mm)

**Table 21: Strength (kN) of Circular HSS Columns Filled with Bar-Reinforced Carbonate Concrete Versus Time for Various Steel Outside Diameters, Steel Wall Thicknesses and Percentage Reinforcing Steel
(Effective Length of Column: 2.5m, Concrete Strength: 55MPa, Concrete Cover: 20mm)**

Time (min)	168			219			273			324			365			408				
	Wall Thickness (mm)			Wall Thickness (mm)			Wall Thickness (mm)			Wall Thickness (mm)			Wall Thickness (mm)			Wall Thickness (mm)				
	% Steel	% Steel	% Steel	% Steel	% Steel	% Steel	% Steel	% Steel	% Steel	% Steel	% Steel	% Steel	% Steel	% Steel	% Steel	% Steel	% Steel	% Steel		
2.0	2.6	5.1	2.3	2.6	5.7	1.2	2.6	5.2	1.4	3.0	6.1	1.3	2.6	5.6	1.5	2.6	6.2	1.6		
3.0	1632	1885	2024	2408	2440	2581	2948	3113	3414	4224	4465	4748	4966	5121	5076	6283	6590	7094	6626	
4.0	1493	1551	1719	1907	1936	2038	2096	2042	3151	3848	4017	4324	4808	4858	5416	5897	6145	6073	6444	
5.0	1113	1137	1318	1184	1191	1480	2242	2411	2858	3010	3187	3656	4022	4275	4905	5044	5274	5804	6119	
6.0	601	657	760	691	724	791	1787	1865	2044	2182	2308	2739	3453	3698	4153	4562	4816	5183	5602	
7.0	363	432	620	461	580	550	1434	1518	1848	1182	1380	1914	2831	3188	3591	3898	3644	4830	4943	
8.0	256	288	373	249	358	428	11865	1223	1319	1078	1158	1421	2683	2844	3146	3279	313	4238	4578	
9.0	195	211	276	182	210	302	919	958	988	870	1087	2259	2422	2709	2458	2857	3884	4154	4854	4245
10.0	152	164	219	147	163	247	752	789	806	496	626	837	1974	2124	2354	1978	2083	2300	350	3751
11.0	120	132	179	120	139	200	638	842	698	505	688	498	1758	1881	2084	1879	1785	1954	3214	3481
12.0	85	103	144	84	104	162	545	549	604	426	428	577	1572	1673	1864	1447	1531	1670	3026	3231
13.0	78	85	121	75	87	130	470	498	618	560	258	482	1408	1486	1540	1484	1540	1484	3024	3352
14.0	67	73	106	64	72	106	396	414	449	500	283	406	1287	1559	1508	1129	1191	1321	2854	2806
15.0	57	61	91	49	56	87	326	345	372	238	245	338	1140	1215	1368	984	1046	1178	2458	2834
16.0	49	50	79	44	49	79	300	320	340	220	220	300	1013	1091	1223	862	919	1026	2311	2447
17.0	44	44	64	40	44	64	260	280	300	170	170	260	901	970	1065	742	785	883	2147	2276
18.0	40	40	59	36	40	59	230	250	270	130	130	230	797	856	974	642	683	784	1736	1835
19.0	36	36	54	32	36	54	200	220	240	100	100	200	712	780	868	573	612	711	1879	2003
20.0	32	32	50	28	32	50	170	190	210	80	80	170	651	710	814	563	617	664	1757	1854
21.0	28	28	46	24	28	46	140	160	180	60	60	140	593	652	768	472	508	584	1841	1741
22.0	24	24	42	20	24	42	110	130	150	40	40	110	593	652	768	436	472	558	1846	1746
23.0	20	20	38	16	20	38	80	100	120	20	20	80	563	621	731	386	426	511	1851	1751
24.0	16	16	34	12	16	34	60	80	100	20	20	60	533	591	701	354	414	504	1856	1756
25.0	12	12	30	8	12	30	40	60	80	20	20	40	503	561	671	324	384	474	1861	1761
26.0	8	8	26	4	8	26	20	40	60	20	20	40	493	521	631	294	354	444	1866	1766
27.0	4	4	22	2	4	22	10	20	30	20	20	30	483	511	621	264	324	414	1871	1771
28.0	2	2	18	1	2	18	8	16	24	20	20	32	473	501	611	234	294	384	1876	1776
29.0	1	1	16	1	1	16	6	10	14	10	10	20	463	491	601	204	264	374	1881	1781
30.0	1	1	14	1	1	14	5	8	12	10	10	18	453	481	591	192	252	362	1886	1786
31.0	1	1	12	1	1	12	4	6	10	8	8	16	443	471	581	181	241	351	1891	1791
32.0	1	1	10	1	1	10	3	5	8	7	7	14	433	461	571	170	230	341	1896	1796
33.0	1	1	8	1	1	8	2	4	6	5	5	10	423	451	561	159	220	331	1901	1801
34.0	1	1	6	1	1	6	1	2	4	3	3	6	413	441	551	149	210	321	1906	1806
35.0	1	1	4	1	1	4	1	1	2	2	2	4	403	431	541	139	200	310	1911	1811
36.0	1	1	2	1	1	2	1	1	1	1	1	2	393	421	531	129	190	290	1916	1816
37.0	1	1	0	1	1	0	1	0	1	0	1	1	383	411	521	119	180	280	1921	1821
38.0	1	1	-	1	1	-	1	-	1	-	1	-	373	401	511	109	170	270	1926	1826
39.0	1	1	-	1	1	-	1	-	1	-	1	-	363	391	501	99	160	260	1931	1831
40.0	1	1	-	1	1	-	1	-	1	-	1	-	353	381	491	89	150	250	1936	1836
41.0	1	1	-	1	1	-	1	-	1	-	1	-	343	371	481	79	140	240	1941	1841
42.0	1	1	-	1	1	-	1	-	1	-	1	-	333	361	471	69	130	230	1946	1846
43.0	1	1	-	1	1	-	1	-	1	-	1	-	323	351	461	59	120	220	1951	1851
44.0	1	1	-	1	1	-	1	-	1	-	1	-	313	341	451	49	110	210	1956	1856
45.0	1	1	-	1	1	-	1	-	1	-	1	-	303	331	441	39	100	200	1961	1861
46.0	1	1	-	1	1	-	1	-	1	-	1	-	293	321	431	29	90	190	1966	1866
47.0	1	1	-	1	1	-	1	-	1	-	1	-	283	311	421	19	80	180	1971	1871
48.0	1	1	-	1	1	-	1	-	1	-	1	-	273	301	411	9	70	170	1976	1876
49.0	1	1	-	1	1	-	1	-	1	-	1	-	263	291	401	0	60	160	1981	1881
50.0	1	1	-	1	1	-	1	-	1	-	1	-	253	281	391	-	50	150	1986	1886
51.0	1	1	-	1	1	-	1	-	1	-	1	-	243	271	381	-	40	140	1991	1891
52.0	1	1	-	1	1	-	1	-	1	-	1	-	233	261	371	-	30	130	1996	1896
53.0	1	1	-	1	1	-	1	-	1	-	1	-	223	251	361	-	20	120	2001	1901
54.0	1	1	-	1	1	-	1	-	1	-	1	-	213	241	351	-	10	110	2006	1906
55.0	1	1	-	1	1	-	1	-	1	-	1	-	203	231	341	-	0	100	2011	1911
56.0	1	1	-	1	1	-	1	-	1	-	1	-	193	221	331	-	-	90	2016	1916
57.0	1	1	-	1	1	-	1	-	1	-	1	-	183	211	321	-	-	80	2021	1921
58.0	1	1	-	1	1	-	1	-	1	-	1	-	173	201	311	-	-	70	2026	1926
59.0	1	1	-	1	1	-	1	-	1	-	1	-	163	191	301	-	-	60	2031	1931
60.0	1	1	-	1	1	-	1	-	1	-	1	-	153	181	291	-	-	50	2036	1936
61.0	1	1	-	1	1	-	1	-	1	-	1	-	143	171	281	-	-	40	2041	1941
62.0	1	1	-	1	1	-	1	-	1	-	1	-	133	163	271	-	-	30	2046	1946
63.0	1	1	-	1	1	-	1	-	1	-	1	-	123	153	261	-	-	20	2051	1951
64.0	1	1	-	1	1	-	1	-	1	-	1	-	113	143	251	-	-	10	2056	1956
65.0	1	1	-	1	1	-	1	-	1	-	1	-	103	133	241	-	-	0	2061	1961
66.0	1	1	-	1	1	-	1	-	1	-	1	-	93	123						

Table 22: Strength (kN) of Circular HSS Columns Filled with Bar-Reinforced Carbonate Concrete Versus Time for Various Steel Outside Diameters, Steel Wall Thicknesses and Percentage Reinforcement Steel (Effective Length of Column: 3.0m, Concrete Strength: 20MPa, Concrete Cover: 20mm)

Time (min)	Outside Diameter (mm)												406																										
	168				219				273				324				356				406																		
	Wall Thickness (mm)	% Steel	Wall Thickness (mm)	% Steel	Wall Thickness (mm)	% Steel	Wall Thickness (mm)	% Steel	Wall Thickness (mm)	% Steel	Wall Thickness (mm)	% Steel	Wall Thickness (mm)	% Steel	Wall Thickness (mm)	% Steel	Wall Thickness (mm)	% Steel	Wall Thickness (mm)	% Steel	Wall Thickness (mm)	% Steel	Wall Thickness (mm)	% Steel															
2.0	4.8	2.5	5.1	2.5	5.7	1.2	2.8	5.2	1.4	3.0	6.1	1.3	2.8	5.6	1.5	2.9	6.2	1.6	2.6	5.3	1.7	2.8	6.4	1.4	3.1	6.8	1.5	2.9	5.8	1.6	3.0	6.2							
3.0	1180	1207	1361	1381	1938	1762	1830	2222	3226	3388	3875	3004	3244	3792	4550	4783	5358	4048	4330	6059	5078	6257	6098	4826	6158	6034	6003	7334	8201	5796	8443	7779	8354	9009	10337				
4.0	800	837	984	1336	1351	1458	1488	1877	1974	2736	2880	3155	2684	2969	3502	4101	4352	4892	3758	4048	4761	5529	5810	6510	4343	4854	5703	6346	6855	7707	6502	8128	7428	7859	8450	9791	8430	9711	10338
5.0	422	471	617	784	783	852	1113	1291	1561	1848	1959	2313	2161	2405	2008	3249	3516	4064	4132	3453	4137	4551	4874	5686	3691	4190	4879	6292	5782	6577	4784	5395	6613	6894	7290	8538			
6.0	215	252	422	436	452	423	614	784	985	1182	1281	1655	1616	1973	2314	2384	2618	3115	2577	2903	3546	3580	3947	4690	3094	3514	4212	4263	4701	5390	4095	4934	5737	5597	6149	7286			
7.0	187	189	321	285	303	325	440	540	726	795	809	1289	1283	1482	1636	1650	1835	2274	2159	2460	3030	3278	3133	3684	2658	3018	3603	3474	3838	4212	3629	4126	5137	4889	5191	6226			
8.0	67	68	149	251	219	230	257	317	424	572	614	649	996	1065	1218	1508	1198	1401	1797	1921	2180	2574	2337	2821	3092	2422	2748	3257	2987	3307	3802	3583	3763	4650	4075	4511	5400		
9.0	100	120	201	138	123	191	227	318	432	443	507	611	870	975	1217	931	1120	1457	1629	1876	2311	2034	2296	2654	2111	2368	2848	2683	3206	3033	3440	4283	3708	4114	4934	3708	4283	5058	
10.0	83	100	167	92	101	154	186	282	362	261	377	617	712	786	1011	678	855	1119	1400	1609	1989	1582	1774	2133	1851	2086	2405	2151	2388	2777	2689	3034	3756	3144	3850	4243			
11.0	70	80	141	76	84	131	159	228	313	207	312	501	590	607	881	546	676	911	1245	1449	1759	1320	1511	1787	1867	2233	1797	2013	2336	2478	2801	3481	2710	3027	3702				
12.0	57	68	116	59	69	106	137	195	272	171	256	415	512	637	787	463	577	790	1122	1268	1574	1148	1287	1542	1748	2061	1585	1788	2068	2305	2617	3226	2422	2728	3215				
13.0	49	56	101	49	56	91	118	168	240	142	208	344	450	477	706	598	499	694	1014	1166	1435	1006	1137	1572	1418	160	1976	1419	1679	1853	2176	2455	3030	3225	2490	3058			
14.0	43	51	88	40	46	80	101	210	115	165	280	397	432	641	302	435	616	822	1002	1295	882	1011	1246	1319	1483	1759	1287	1440	1685	2056	2234	2837	2906	2931	2816				
15.0	37	44	76	32	39	64	84	123	162	82	120	223	357	398	685	296	383	544	849	975	1184	787	900	1148	1213	1364	1603	1168	1300	1518	1938	2163	2866	1899	2135	2578			
16.0	30	37	68	22	29	56	64	84	106	137	195	272	171	256	415	512	637	787	463	577	790	1122	1268	1574	1148	1287	1542	1748	2061	1585	1788	2068	2305	2617	2728	3215			
17.0	24	30	56	22	29	56	64	84	106	137	195	272	171	256	415	512	637	787	463	577	790	1122	1268	1574	1148	1287	1542	1748	2061	1585	1788	2068	2305	2617	2728	3215			
18.0	21	24	51	22	29	56	64	84	106	137	195	272	171	256	415	512	637	787	463	577	790	1122	1268	1574	1148	1287	1542	1748	2061	1585	1788	2068	2305	2617	2728	3215			
19.0	19	21	49	22	29	56	64	84	106	137	195	272	171	256	415	512	637	787	463	577	790	1122	1268	1574	1148	1287	1542	1748	2061	1585	1788	2068	2305	2617	2728	3215			
20.0	17	19	47	22	29	56	64	84	106	137	195	272	171	256	415	512	637	787	463	577	790	1122	1268	1574	1148	1287	1542	1748	2061	1585	1788	2068	2305	2617	2728	3215			
21.0	16	17	45	22	29	56	64	84	106	137	195	272	171	256	415	512	637	787	463	577	790	1122	1268	1574	1148	1287	1542	1748	2061	1585	1788	2068	2305	2617	2728	3215			
22.0	15	16	43	22	29	56	64	84	106	137	195	272	171	256	415	512	637	787	463	577	790	1122	1268	1574	1148	1287	1542	1748	2061	1585	1788	2068	2305	2617	2728	3215			
23.0	14	15	41	22	29	56	64	84	106	137	195	272	171	256	415	512	637	787	463	577	790	1122	1268	1574	1148	1287	1542	1748	2061	1585	1788	2068	2305	2617	2728	3215			
24.0	13	14	39	22	29	56	64	84	106	137	195	272	171	256	415	512	637	787	463	577	790	1122	1268	1574	1148	1287	1542	1748	2061	1585	1788	2068	2305	2617	2728	3215			
25.0	12	13	37	22	29	56	64	84	106	137	195	272	171	256	415	512	637	787	463	577	790	1122	1268	1574	1148	1287	1542	1748	2061	1585	1788	2068	2305	2617	2728	3215			
26.0	11	12	35	22	29	56	64	84	106	137	195	272	171	256	415	512	637	787	463	577	790	1122	1268	1574	1148	1287	1542	1748	2061	1585	1788	2068	2305	2617	2728	3215			
27.0	10	11	33	22	29	56	64	84	106	137	195	272	171	256	415	512	637	787	463	577	790	1122	1268	1574	1148	1287	1542	1748	2061	1585	1788	2068	2305	2617	2728	3215			
28.0	9	10	31	22	29	56	64	84	106	137	195	272	171	256	415	512	637	787	463	577	790	1122	1268	1574	1148	1287	1542	1748	2061	1585	1788	2068	2305	2617	2728	3215			
29.0	8	9	29	22	29	56	64	84	106	137	195	272	171	256	415	512	637	787	463	577	790	1122	1268	1574	1148	1287	1542	1748	2061	1585	1788	2068	2305	2617	2728	3215			
30.0	7	8	27	22	29	56	64	84	106	137	195	272	171	256	415	512	637	787	463	577	790	1122	1268	1574	1148	1287	1542	1748	2061	1585	1788	2068	2305	2617	2728	3215			
31.0	6	7	25	22	29	56	64	84	106	137	195	272	171	256	415	512	637	787	463	577	790	1122	1268	1574	1148	1287	1542	1748	2061	1585	1788	2068	2305	2617	2728	3215			
32.0	5	6	23	22	29	56	64	84	106	137	195	272	171	256	415	512	637	787	463	577	790	1122	1268	1574	1148	1287	1542	1748	2061	1585	1788	2068	2305	2617	2728	3215			
33.0	4	5	21	22	29	56	64	84	106	137	195	272	171	256	415	512	637	787	463	577	790	1122	1268	1574	1148	1287	1542	1748	2061	1585	1788	2068</							

**Table 23: Strength (kN) of Circular HSS Columns Filled with Bar-Reinforced Carbonate Reinforcing Steel
Outside Diameters, Steel Wall Thicknesses and Percentage Reinforcement
(Effective Length of Column: 3.0m, Concrete Strength: 35MPa, Concrete Cover: 20mm)**

Time (min)	Outside diameter (mm)												406						
	168			219			273			324			356		Wall thickness (mm)				
	Wall Thickness (mm)	% Steel	% Steel	Wall Thickness (mm)	% Steel	% Steel	Wall Thickness (mm)	% Steel	% Steel	Wall Thickness (mm)	% Steel	% Steel	Wall Thickness (mm)	% Steel	Wall Thickness (mm)	% Steel			
2.0	4.8	5.1	5.7	1.2	2.6	5.2	1.4	3.0	6.1	1.3	2.8	5.6	1.5	2.9	6.2	1.7			
3.0	1418	1449	1567	2045	2191	2397	2886	3612	3774	4059	3748	3963	4529	5201	6445	5887	6139		
4.0	1000	1039	1179	1470	1495	1615	1921	2063	2388	3049	3218	3610	3432	3865	4236	4753	5002	5547	
5.0	390	480	530	634	853	917	1498	1643	1938	2057	2378	2673	2829	3074	3582	3863	4107	4848	
6.0	283	303	477	469	490	498	1038	1132	1256	1339	1434	2053	2281	2495	2936	2971	3167	3647	
7.0	195	220	366	308	320	333	620	708	880	888	880	1372	1875	2058	2225	2396	2720	3120	
8.0	145	171	276	229	241	285	442	538	676	678	679	691	1102	1612	1782	2020	1820	1754	2126
9.0	114	131	219	145	120	185	342	405	522	382	529	869	1312	1434	1847	1228	1384	1722	2481
10.0	70	82	106	181	92	104	158	280	332	436	258	404	845	1107	1216	1042	1068	1346	2151
11.0	78	90	145	77	87	133	232	284	375	214	326	523	957	1022	1054	851	765	1112	1981
12.0	62	73	126	60	69	112	224	248	328	177	284	428	636	905	624	742	717	968	1782
13.0	61	60	105	49	57	94	201	212	285	150	216	353	724	790	815	657	634	848	1627
14.0	45	56	90	42	48	63	176	184	250	121	188	287	648	708	571	683	765	1491	1895
15.0	39	45	78	34	40	71	149	154	214	84	131	230	676	638	505	617	686	1398	1600
16.0	31	39	96	35	45	85	194	201	241	104	131	240	610	569	443	612	483	1298	1580
17.0	28	32	92	30	36	290	366	380	398	919	1014	1179	871	795	656	821	785	1117	1122
18.0	287	330	368	235	257	365	848	945	1103	607	400	517	1158	1273	1482	1010	1116	1280	1747
19.0	351	398	435	283	305	421	982	1091	1267	920	1082	1549	1862	1343	1267	1343	1267	1586	1988
20.0	317	382	396	290	306	388	919	1014	1179	756	851	1006	1460	1578	1746	1145	1228	1360	1883
21.0	314	380	396	283	305	388	916	1013	1176	691	780	915	1485	1680	1883	1070	1145	1270	1897
22.0	359	445	490	314	345	458	1065	1171	1354	906	1008	1160	1841	1771	1984	1447	1587	1737	2394
23.0	351	398	435	283	305	421	982	1091	1267	920	1082	1549	1862	1343	1267	1343	1267	1586	1988
24.0	317	382	396	290	306	388	919	1014	1179	756	851	1006	1460	1578	1746	1145	1228	1360	1883
25.0	314	380	396	283	305	388	916	1013	1176	691	780	915	1485	1680	1883	1070	1145	1270	1897
26.0	359	445	490	314	345	458	1065	1171	1354	906	1008	1160	1841	1771	1984	1447	1587	1737	2394
27.0	351	398	435	283	305	421	982	1091	1267	920	1082	1549	1862	1343	1267	1343	1267	1586	1988
28.0	317	382	396	290	306	388	919	1014	1179	756	851	1006	1460	1578	1746	1145	1228	1360	1883
29.0	314	380	396	283	305	388	916	1013	1176	691	780	915	1485	1680	1883	1070	1145	1270	1897
30.0	359	445	490	314	345	458	1065	1171	1354	906	1008	1160	1841	1771	1984	1447	1587	1737	2394
31.0	351	398	435	283	305	421	982	1091	1267	920	1082	1549	1862	1343	1267	1343	1267	1586	1988
32.0	317	382	396	290	306	388	919	1014	1179	756	851	1006	1460	1578	1746	1145	1228	1360	1883
33.0	314	380	396	283	305	388	916	1013	1176	691	780	915	1485	1680	1883	1070	1145	1270	1897
34.0	359	445	490	314	345	458	1065	1171	1354	906	1008	1160	1841	1771	1984	1447	1587	1737	2394
35.0	351	398	435	283	305	421	982	1091	1267	920	1082	1549	1862	1343	1267	1343	1267	1586	1988
36.0	317	382	396	290	306	388	919	1014	1179	756	851	1006	1460	1578	1746	1145	1228	1360	1883
37.0	314	380	396	283	305	388	916	1013	1176	691	780	915	1485	1680	1883	1070	1145	1270	1897
38.0	359	445	490	314	345	458	1065	1171	1354	906	1008	1160	1841	1771	1984	1447	1587	1737	2394
39.0	351	398	435	283	305	421	982	1091	1267	920	1082	1549	1862	1343	1267	1343	1267	1586	1988
40.0	317	382	396	290	306	388	919	1014	1179	756	851	1006	1460	1578	1746	1145	1228	1360	1883
41.0	314	380	396	283	305	388	916	1013	1176	691	780	915	1485	1680	1883	1070	1145	1270	1897
42.0	359	445	490	314	345	458	1065	1171	1354	906	1008	1160	1841	1771	1984	1447	1587	1737	2394
43.0	351	398	435	283	305	421	982	1091	1267	920	1082	1549	1862	1343	1267	1343	1267	1586	1988
44.0	317	382	396	290	306	388	919	1014	1179	756	851	1006	1460	1578	1746	1145	1228	1360	1883
45.0	314	380	396	283	305	388	916	1013	1176	691	780	915	1485	1680	1883	1070	1145	1270	1897
46.0	359	445	490	314	345	458	1065	1171	1354	906	1008	1160	1841	1771	1984	1447	1587	1737	2394
47.0	351	398	435	283	305	421	982	1091	1267	920	1082	1549	1862	1343	1267	1343	1267	1586	1988
48.0	317	382	396	290	306	388	919	1014	1179	756	851	1006	1460	1578	1746	1145	1228	1360	1883
49.0	314	380	396	283	305	388	916	1013	1176	691	780	915	1485	1680	1883	1070	1145	1270	1897
50.0	359	445	490	314	345	458	1065	1171	1354	906	1008	1160	1841	1771	1984	1447	1587	1737	2394
51.0	351	398	435	283	305	421	982	1091	1267	920	1082	1549	1862	1343	1267	1343	1267	1586	1988
52.0	317	382	396	290	306	388	919	1014	1179	756	851	1006	1460	1578	1746	1145	1228	1360	1883
53.0	314	380	396	283	305	388	916	1013	1176	691	780	915	1485	1680	1883	1070	1145	1270	1897
54.0	359	445	490	314	345	458	1065	1171	1354	906	1008	1160	1841	1771	1984	1447	1587	1737	2394
55.0	351	398	435	283	305	421	982	1091	1267	920	1082	1549	1862	1343	1267	1343	1267	1586	1988
56.0	317	382	396	290	306	388	919	1014	1179	756	851	1006	1460	1578	1746	1145	1228	1360	1883
57.0	314	380	396	283	305	388	916	1013	1176	691	780	915	1485	1680	1883	1070	1145	1270	1897
58.0	359	445	490	314	345	458	1065	1171	1354	906	1008	1160	1841	1771	1984	1447	1587	1737	2394
59.0	351	398	435	283	305	421	982	1091	1267	920	1082	1549	1862	1343	1267	1343	1267	1586	1988
60.0	317	382	396	290	306	388	919	1014	1179	756	851	1006	1460	1578	1746	1145	1228	1360	1883
61.0	314	380	3																

Table 24: Strength (kN) of Circular HSS Columns Filled with Bar-Reinforced Carbonate Concrete Versus Time for Various Steel Outside Diameters, Steel Wall Thicknesses and Percentage Reinforcing Steel
 (Effective Length of Column: 3.0m, Concrete Strength: 55MPa, Concrete Cover: 20mm)

Table 25: Strength (kN) of Circular HSS Columns Filled with Bar-Reinforced Carbonate Concrete Versus Time for Various Steel Outside Diameters, Steel Wall Thicknesses and Percentage Reinforcing Steel
 (Effective Length of Column: 4.5m, Concrete Strength: 20MPa, Concrete Cover: 20mm)

**Table 26: Strength (kN) of Circular HSS Columns Filled with Bar-Reinforced Carbonate Reinforcing Steel
Outside Diameters, Steel Wall Thicknesses and Percentage Reinforcing Steel
(Effective Length of Column: 4.5m, Concrete Strength: 35MPa, Concrete Cover: 20mm)**

Time (min)	Outside Diameter (mm)												406																								
	168				219				273				324				356				406																
	Wall Thickness (mm)	% Steel	Wall Thickness (mm)	% Steel	Wall Thickness (mm)	% Steel	Wall Thickness (mm)	% Steel	Wall Thickness (mm)	% Steel	Wall Thickness (mm)	% Steel	Wall Thickness (mm)	% Steel	Wall Thickness (mm)	% Steel	Wall Thickness (mm)	% Steel	Wall Thickness (mm)	% Steel	Wall Thickness (mm)	% Steel	Wall Thickness (mm)	% Steel													
2.0	4.8	2.5	5.1	2.3	2.9	5.7	1.2	2.6	5.2	1.4	3.0	6.1	1.3	2.6	5.6	1.5	2.8	6.2	1.6	2.6	5.3	1.7	2.9	6.7	1.4	3.1	6.8	1.6	2.9	5.8	1.6	3.0	6.2				
5	1237	1262	1370	1662	1878	1984	2140	2403	3277	3427	3608	3402	3626	4195	4748	4977	5469	4778	5037	5686	5466	6723	7391	5587	6077	6890	7487	7986	8775	7229	7820	8051	9446	10036	11242		
10	565	678	653	1074	1069	1059	1348	1483	1704	2417	2512	2678	2817	3108	3718	3941	4166	4616	4297	4847	5243	5732	6074	6843	5190	5659	6453	6863	7388	8141	6559	7420	8618	8900	9477	10679	
20	247	251	273	562	528	502	601	636	1278	1337	1408	1136	2029	2461	3059	2497	2858	3543	3487	3913	4578	4554	5002	5071	4385	4789	5527	5579	6110	6906	5069	5523	7841	7565	9057	9231	
30	132	138	194	288	295	270	316	462	682	784	824	890	721	1785	2173	1568	1942	2364	2792	3232	3850	3340	4036	4763	3640	3981	4484	4404	4729	5299	6167	5829	6547	6281	6743	7877	
40	94	99	149	168	154	154	173	223	345	520	488	524	582	517	1131	1514	1388	987	1745	2277	2578	3244	1489	2222	3468	3059	3319	3728	3615	3782	4192	4592	4981	5811	5349	5745	6598
50	63	65	117	118	122	137	141	278	424	472	401	484	419	897	1224	775	840	1394	1973	2152	2307	1168	2006	2572	2719	2888	3331	3015	3205	3886	4136	4482	6173	4677	4914	5581	
60	44	52	93	72	74	85	106	218	337	257	284	368	301	641	926	596	719	1184	1898	1784	1951	946	1638	2076	2371	2657	2811	2846	2862	3794	4103	4703	4168	4445	5082		
70	36	43	78	56	58	71	92	188	290	159	176	313	237	491	745	348	582	934	1374	1080	1583	681	1200	1822	2068	2235	2446	2136	2220	1862	3330	5588	4119	3536	3798	4276	
80	30	36	66	48	60	63	83	160	252	120	148	273	191	406	628	307	482	761	1178	938	1388	528	1002	1350	1830	1982	2081	1768	1213	1525	3074	5315	3772	3111	3525	3766	
100	22	27	48	21	25	42	63	121	190	75	105	202	141	315	490	244	390	556	814	718	1086	743	1010	1474	1555	1240	1357	1006	1153	2408	2787	3181	2516	2678	3018		
150	19	23	42	18	21	37	59	104	172	53	92	174	117	277	427	212	303	478	798	840	989	944	658	914	1382	1399	1129	1180	1048	1041	2430	2695	2803	2436	2771		
200	17	21	39	15	18	32	48	86	151	40	74	163	98	249	382	177	253	412	674	685	761	447	602	828	1228	1217	1045	1011	943	943	2248	2414	2718	2988	2219	2430	
300	14	16	34	10	12	18	26	46	82	124	231	185	366	549	285	418	647	800	1203	413	846	1156	1649	1787	1398	1582	729	1328	2810	3014	3430	2765	2942	3316			
400	11	13	29	8	10	14	22	37	63	121	190	75	105	202	141	315	490	244	390	556	814	718	1086	743	1010	1474	1555	1240	1357	1006	1153	2408	2787	3181	2516	2678	3018
500	9	11	26	6	8	12	20	35	60	118	187	153	222	398	631	961	136	227	384	651	811	937	1393	1586	1786	1398	1680	2107	2252	2502	2877	3181	2516	2678	3018		
600	7	9	23	4	6	10	18	32	57	112	181	147	216	381	615	947	132	222	377	648	808	934	1394	1586	1786	1398	1680	2107	2252	2502	2877	3181	2516	2678	3018		
700	6	7	21	3	5	9	16	30	55	107	176	142	211	376	609	921	129	219	371	641	801	926	1394	1586	1786	1398	1680	2107	2252	2502	2877	3181	2516	2678	3018		
800	5	6	19	2	4	8	14	28	52	99	167	133	202	367	603	913	127	207	359	631	791	911	1391	1583	1783	1395	1677	2095	2245	2495	2855	3165	2515	2675	3015		
900	4	5	17	1	3	6	12	26	50	96	164	130	199	362	600	893	124	204	354	624	784	904	1384	1576	1776	1386	1668	2086	2236	2486	2846	3156	2514	2674	3014		
1000	3	4	15	0	2	5	11	24	48	93	161	127	196	357	600	883	120	200	348	613	773	893	1373	1565	1765	1375	1657	2075	2225	2475	2835	3145	2512	2672	3012		
1200	2	3	13	-	1	4	9	22	45	88	156	122	191	352	597	873	116	196	343	608	768	888	1368	1558	1758	1368	1648	2068	2218	2468	2828	3138	2510	2670	3010		
1500	1	2	11	-	0	3	8	19	42	83	151	117	186	347	592	858	115	195	338	593	753	873	1353	1543	1743	1353	1633	2053	2203	2453	2813	3123	2508	2668	3008		
2000	-	1	9	-	0	2	7	18	41	76	145	113	182	342	587	843	114	194	333	588	748	868	1343	1533	1733	1343	1623	2043	2193	2443	2703	3013	2507	2667	3007		
3000	-	-	7	-	0	1	6	17	39	71	140	108	177	337	582	838	113	193	328	583	743	863	1333	1523	1723	1333	1613	2033	2183	2433	2693	3003	2506	2666	3006		
4000	-	-	5	-	0	1	5	16	38	69	138	106	176	332	577	833	112	192	323	578	738	858	1323	1513	1713	1323	1603	2023	2173	2423	2683	3003	2505	2665	3005		
5000	-	-	3	-	0	1	4	15	37	68	136	104	175	327	572	828	111	191	318	573	733	853	1313	1503	1703	1313	1593	2013	2163	2413	2673	3003	2504	2664	3004		
7000	-	-	1	-	0	1	3	14	36	67	134	103	174	322	567	823	110	190	313	568	728	848	1303	1493	1693	1303	1483	2003	2153	2403	2663	3003	2503	2663	3003		
10000	-	-	-	-	0	1	2	13	35	66	132	102	173	317	562	818	109	189	308	563	723	843	1293	1483	1683	1293	1473	2003	2153	2403	2663	3003	2503	2663	3003		
15000	-	-	-	-	0	1	1	12	34	65	130	101	172	312	557	813	108	188	303	558	718	838	1283	1473	1673	1283	1463	2003	2153	2403	2663	3003	2503	2663	3003		
20000	-	-	-	-	0	1	0	11	33	64	129	100	171	307	552	808	107	187	300	553	713	828	1273	1463	1663	1273	1453	2003	2153	2403	2663	3003	2503	2663	3003		
30000	-	-	-	-	0	1	0	10	32	63	128	99	170	302	547	803	106	186	297	548	708	818	1263	1453	1653	1263	1443	2003	2153	2403	2663	3003	2503	2663	3003		
40000	-	-	-	-	0	1	0	9	31	62	127	98	169	297	542	802	105	185	292	543	703	813	1253	1443	1643	1253	1433	2003	2153	2403	2663	3003	2503	2663	3003		
50000	-	-	-	-	0	1	0	8	30	61	126	97	168	292	537	801	104	184	287																		

**Table 27: Strength (kN) of Circular HSS Columns Filled with Bar-Reinforced Carbonate Concrete Versus Time for Various Steel Outside Diameters, Steel Wall Thicknesses and Percentage Reinforcing Steel
(Effective Length of Column: 4.5m, Concrete Strength: 55MPa, Concrete Cover: 20mm)**

Time (min)	Outside Diameter (mm)						Wall Thickness (mm)						Wall Thickness (mm)						Wall Thickness (mm)																	
	198			210			219			273			324			355			406																	
	Wall Thickness (mm)	Steel %	Steel %	Wall Thickness (mm)	Steel %	Steel %	Wall Thickness (mm)	Steel %	Steel %	Wall Thickness (mm)	Steel %	Steel %	Wall Thickness (mm)	Steel %	Steel %	Wall Thickness (mm)	Steel %	Steel %	Wall Thickness (mm)	Steel %	Steel %	Wall Thickness (mm)	Steel %	Steel %												
4.8	2.0	5.1	2.5	2.9	6.7	1.2	2.6	6.2	1.4	3.0	6.1	1.3	2.6	5.6	1.5	2.9	6.2	1.6	2.6	5.9	1.7	2.8	6.4	1.4	3.1	5.8	1.5	2.9	5.8	1.3	3.0	6.2				
5.1	1427	1442	1560	2050	2042	2171	2562	2649	2806	3732	3876	4127	4286	4523	5028	5543	5759	6284	6104	6372	7007	7669	7939	8615	7276	7765	8640	9038	9510	10311	9491	1091	11284	11582	12132	13564
5.4	652	669	746	1068	1127	1787	1917	2126	2713	2604	2984	3622	3910	4501	4824	4867	6312	5568	5941	6616	6920	7258	7987	8807	7280	8061	8350	8880	8864	9102	8689	10870	10941	11573	12749	
5.7	273	283	306	562	528	536	1275	1423	1689	1482	1636	1206	2730	3166	5744	5370	3648	4217	4986	5090	6756	5885	6104	6886	6357	7067	7058	7476	8198	8175	8735	9842	9577	10128	11238	
6.0	144	148	219	288	265	286	389	550	785	829	885	949	2113	2338	2791	1787	1600	3844	3922	4205	4916	4409	4954	5683	5121	6403	6959	6764	6827	7236	7693	8639	8273	8720	9712	
6.3	100	108	166	168	169	187	256	402	658	610	551	601	610	1392	1741	1147	1137	2034	3264	3536	3973	3478	3792	4270	4409	4854	5074	4778	5049	5483	6590	6558	7809	7196	7811	8487
6.6	63	68	124	118	126	142	159	325	491	383	420	509	458	1122	1342	870	1028	1569	2825	3003	5246	2857	3047	3169	3898	4205	4560	4168	4378	4703	5988	6308	6958	6225	6451	7351
6.9	45	54	99	74	77	87	120	243	356	285	299	404	837	754	1027	847	831	1255	2449	2564	2812	1024	1988	2475	3455	3843	3944	3670	3751	3980	5654	5857	4473	5811	6107	6731
7.2	37	45	80	55	60	73	109	207	309	165	178	333	253	904	830	367	551	980	2090	2174	1751	715	1558	1986	3079	3222	3479	3670	3208	3371	4926	5193	5658	5026	5580	6795
7.5	31	39	68	44	47	60	93	177	261	127	149	235	203	505	704	372	622	796	1784	1854	1536	1361	1304	1881	2723	2878	3088	2727	2839	4585	4811	5321	4486	4720	5221	
7.8	26	32	57	32	31	50	63	163	235	101	128	246	306	441	628	326	452	872	1581	1487	1580	1580	1098	1395	2495	2580	2768	2338	1801	4204	4408	4832	4028	4211	4612	
8.1	22	27	50	21	25	43	81	120	206	80	108	214	361	392	565	272	383	573	1341	1278	1362	1005	963	1223	2223	2321	2421	2037	2096	1564	3837	4128	4506	3686	3875	4250
8.4	20	24	45	18	21	37	67	112	179	63	93	185	323	348	499	233	319	438	1177	1143	1256	899	815	1114	2053	2128	2122	1811	1806	1394	3489	3888	4217	3409	3598	3903
8.7	16	22	30	15	18	33	53	82	164	40	79	161	284	314	448	183	264	422	1080	1057	1143	841	750	996	1869	1913	1920	1822	1596	1290	3411	3653	3883	9124	3264	3559
9.0	11	14	27	11	14	22	34	54	84	231	406	164	231	370	406	144	231	359	971	978	1043	905	652	682	1080	1745	1725	1487	1457	1360	3227	3339	3649	2911	3046	3323
9.3	10	13	24	11	14	21	32	53	83	231	406	164	231	370	406	144	231	359	971	978	1043	905	652	682	1080	1745	1725	1487	1457	1360	3227	3339	3649	2911	3046	3323
9.6	9	12	23	10	13	20	31	52	82	231	406	164	231	370	406	144	231	359	971	978	1043	905	652	682	1080	1745	1725	1487	1457	1360	3227	3339	3649	2911	3046	3323
9.9	8	11	22	9	12	19	29	51	81	231	406	164	231	370	406	144	231	359	971	978	1043	905	652	682	1080	1745	1725	1487	1457	1360	3227	3339	3649	2911	3046	3323
10.2	7	10	21	8	11	18	28	49	79	231	406	164	231	370	406	144	231	359	971	978	1043	905	652	682	1080	1745	1725	1487	1457	1360	3227	3339	3649	2911	3046	3323
10.5	6	9	19	5	8	16	26	47	77	231	406	164	231	370	406	144	231	359	971	978	1043	905	652	682	1080	1745	1725	1487	1457	1360	3227	3339	3649	2911	3046	3323
10.8	5	8	18	4	7	15	25	46	76	231	406	164	231	370	406	144	231	359	971	978	1043	905	652	682	1080	1745	1725	1487	1457	1360	3227	3339	3649	2911	3046	3323
11.1	4	7	17	3	6	14	24	45	75	231	406	164	231	370	406	144	231	359	971	978	1043	905	652	682	1080	1745	1725	1487	1457	1360	3227	3339	3649	2911	3046	3323
11.4	3	6	16	2	5	13	23	44	74	231	406	164	231	370	406	144	231	359	971	978	1043	905	652	682	1080	1745	1725	1487	1457	1360	3227	3339	3649	2911	3046	3323
11.7	2	5	15	1	4	12	22	43	73	231	406	164	231	370	406	144	231	359	971	978	1043	905	652	682	1080	1745	1725	1487	1457	1360	3227	3339	3649	2911	3046	3323
12.0	1	4	14	0	3	11	21	42	72	231	406	164	231	370	406	144	231	359	971	978	1043	905	652	682	1080	1745	1725	1487	1457	1360	3227	3339	3649	2911	3046	3323

**Table 28: Strength (kN) of Circular HSS Columns Filled with Bar-Reinforced Carbonate Concrete Versus Time for Various Steel Outside Diameters, Steel Wall Thicknesses and Percentage Reinforcement Steel
(Effective Length of Column: 2.5m, Concrete Strength: 20MPa, Concrete Cover: 50mm)**

Time (hrs)	Outside Diameter (mm)						Wall Thickness (mm)						Wall Thickness (mm)						Wall Thickness (mm)																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																	
168	180	192	210	225	240	273	300	324	355	380	406	1.6	1.8	2.0	2.2	2.4	2.6	2.8	3.0	3.2	3.4	3.6	3.8	4.0	4.2	4.4	4.6	4.8	5.0	5.1	5.2	5.3	5.4	5.5	5.6	5.7	5.8	5.9	6.0	6.1	6.2	6.3	6.4	6.5	6.6	6.7	6.8	6.9	7.0	7.1	7.2	7.3	7.4	7.5	7.6	7.7	7.8	7.9	8.0	8.1	8.2	8.3	8.4	8.5	8.6	8.7	8.8	8.9	9.0	9.1	9.2	9.3	9.4	9.5	9.6	9.7	9.8	9.9	10.0	10.1	10.2	10.3	10.4	10.5	10.6	10.7	10.8	10.9	11.0	11.1	11.2	11.3	11.4	11.5	11.6	11.7	11.8	11.9	12.0	12.1	12.2	12.3	12.4	12.5	12.6	12.7	12.8	12.9	13.0	13.1	13.2	13.3	13.4	13.5	13.6	13.7	13.8	13.9	14.0	14.1	14.2	14.3	14.4	14.5	14.6	14.7	14.8	14.9	15.0	15.1	15.2	15.3	15.4	15.5	15.6	15.7	15.8	15.9	16.0	16.1	16.2	16.3	16.4	16.5	16.6	16.7	16.8	16.9	17.0	17.1	17.2	17.3	17.4	17.5	17.6	17.7	17.8	17.9	18.0	18.1	18.2	18.3	18.4	18.5	18.6	18.7	18.8	18.9	19.0	19.1	19.2	19.3	19.4	19.5	19.6	19.7	19.8	19.9	20.0	20.1	20.2	20.3	20.4	20.5	20.6	20.7	20.8	20.9	21.0	21.1	21.2	21.3	21.4	21.5	21.6	21.7	21.8	21.9	22.0	22.1	22.2	22.3	22.4	22.5	22.6	22.7	22.8	22.9	23.0	23.1	23.2	23.3	23.4	23.5	23.6	23.7	23.8	23.9	24.0	24.1	24.2	24.3	24.4	24.5	24.6	24.7	24.8	24.9	25.0	25.1	25.2	25.3	25.4	25.5	25.6	25.7	25.8	25.9	26.0	26.1	26.2	26.3	26.4	26.5	26.6	26.7	26.8	26.9	27.0	27.1	27.2	27.3	27.4	27.5	27.6	27.7	27.8	27.9	28.0	28.1	28.2	28.3	28.4	28.5	28.6	28.7	28.8	28.9	29.0	29.1	29.2	29.3	29.4	29.5	29.6	29.7	29.8	29.9	30.0	30.1	30.2	30.3	30.4	30.5	30.6	30.7	30.8	30.9	31.0	31.1	31.2	31.3	31.4	31.5	31.6	31.7	31.8	31.9	32.0	32.1	32.2	32.3	32.4	32.5	32.6	32.7	32.8	32.9	33.0	33.1	33.2	33.3	33.4	33.5	33.6	33.7	33.8	33.9	34.0	34.1	34.2	34.3	34.4	34.5	34.6	34.7	34.8	34.9	35.0	35.1	35.2	35.3	35.4	35.5	35.6	35.7	35.8	35.9	36.0	36.1	36.2	36.3	36.4	36.5	36.6	36.7	36.8	36.9	37.0	37.1	37.2	37.3	37.4	37.5	37.6	37.7	37.8	37.9	38.0	38.1	38.2	38.3	38.4	38.5	38.6	38.7	38.8	38.9	39.0	39.1	39.2	39.3	39.4	39.5	39.6	39.7	39.8	39.9	40.0	40.1	40.2	40.3	40.4	40.5	40.6	40.7	40.8	40.9	41.0	41.1	41.2	41.3	41.4	41.5	41.6	41.7	41.8	41.9	42.0	42.1	42.2	42.3	42.4	42.5	42.6	42.7	42.8	42.9	43.0	43.1	43.2	43.3	43.4	43.5	43.6	43.7	43.8	43.9	44.0	44.1	44.2	44.3	44.4	44.5	44.6	44.7	44.8	44.9	45.0	45.1	45.2	45.3	45.4	45.5	45.6	45.7	45.8	45.9	46.0	46.1	46.2	46.3	46.4	46.5	46.6	46.7	46.8	46.9	47.0	47.1	47.2	47.3	47.4	47.5	47.6	47.7	47.8	47.9	48.0	48.1	48.2	48.3	48.4	48.5	48.6	48.7	48.8	48.9	49.0	49.1	49.2	49.3	49.4	49.5	49.6	49.7	49.8	49.9	50.0	50.1	50.2	50.3	50.4	50.5	50.6	50.7	50.8	50.9	50.10	50.11	50.12	50.13	50.14	50.15	50.16	50.17	50.18	50.19	50.20	50.21	50.22	50.23	50.24	50.25	50.26	50.27	50.28	50.29	50.30	50.31	50.32	50.33	50.34	50.35	50.36	50.37	50.38	50.39	50.40	50.41	50.42	50.43	50.44	50.45	50.46	50.47	50.48	50.49	50.50	50.51	50.52	50.53	50.54	50.55	50.56	50.57	50.58	50.59	50.60	50.61	50.62	50.63	50.64	50.65	50.66	50.67	50.68	50.69	50.70	50.71	50.72	50.73	50.74	50.75	50.76	50.77	50.78	50.79	50.80	50.81	50.82	50.83	50.84	50.85	50.86	50.87	50.88	50.89	50.90	50.91	50.92	50.93	50.94	50.95	50.96	50.97	50.98	50.99	50.100	50.101	50.102	50.103	50.104	50.105	50.106	50.107	50.108	50.109	50.110	50.111	50.112	50.113	50.114	50.115	50.116	50.117	50.118	50.119	50.120	50.121	50.122	50.123	50.124	50.125	50.126	50.127	50.128	50.129	50.130	50.131	50.132	50.133	50.134	50.135	50.136	50.137	50.138	50.139	50.140	50.141	50.142	50.143	50.144	50.145	50.146	50.147	50.148	50.149	50.150	50.151	50.152	50.153	50.154	50.155	50.156	50.157	50.158	50.159	50.160	50.161	50.162	50.163	50.164	50.165	50.166	50.167	50.168	50.169	50.170	50.171	50.172	50.173	50.174	50.175	50.176	50.177	50.178	50.179	50.180	50.181	50.182	50.183	50.184	50.185	50.186	50.187	50.188	50.189	50.190	50.191	50.192	50.193	50.194	50.195	50.196	50.197	50.198	50.199	50.200	50.201	50.202	50.203	50.204	50.205	50.206	50.207	50.208	50.209	50.210	50.211	50.212	50.213	50.214	50.215	50.216	50.217	50.218	50.219	50.220	50.221	50.222	50.223	50.224	50.225	50.226	50.227	50.228	50.229	50.230	50.231	50.232	50.233	50.234	50.235	50.236	50.237	50.238	50.239	50.240	50.241	50.242	50.243	50.244	50.245	50.246	50.247	50.248	50.249	50.250	50.251	50.252	50.253	50.254	50.255	50.256	50.257	50.258	50.259	50.260	50.261	50.262	50.263	50.264	50.265	50.266	50.267	50.268	50.269	50.270	50.271	50.272	50.273	50.274	50.275	50.276	50.277	50.278	50.279	50.280	50.281	50.282	50.283	50.284	50.285	50.286	50.287	50.288	50.289	50.290	50.291	50.292	50.293	50.294	50.295	50.296	50.297	50.298	50.299	50.300	50.301	50.302	50.303	50.304	50.305	50.306	50.307	50.308	50.309	50.310	50.311	50.312	50.313	50.314	50.315	50.316	50.317	50.318	50.319	50.320	50.321	50.322	50.323	50.324	50.325	50.326	50.327	50.328	50.329	50.330	50.331	50.332	50.333	50.334	50.335	50.336	50.337	50.338	50.339	50.340	50.341	50.342	50.343	50.344	50.345	50.346	50.347	50.348	50.349	50.350	50.351	50.352	50.353	50.354	50.355	50.356	50.357	50.358	50.359	50.360	50.361	50.362	50.363	50.364	50.365	50.366	50.367	50.368	50.369	50.370	50.371	50.372	50.373	50.374	50.375	50.376	50.377	50.378	50.379	50.380	50.381	50.382	50.383	50.384	50.385	50.386	50.387	50.388	50.389	50.390	50.391	50.392	50.393	50.394	50.395	50.396	50.397	50.398	50.399	50.400	50.401	50.402	50.403	50.404	50.405	50.406	50.407	50.408	50.409	50.410	50.411	50.412	50.413	50.414	50.415	50.416	50.417	50.418	50.419	50.420	50.421	50.422	50.423	50.424	50.425	50.426	50.427	50.428	50.429	50.430	50.431	50.432	50.433	50.434	50.435	50.436	50.437	50.438	50.439	50.440	50.441	50.442	50.443	50.444	50.445	50.446	50.447	50.448	50.449	50.450	50.451	50.452	50.453	50.454	50.455	50.456	50.457	50.458	50.459	50.460	50.461	50.462	50.463	50.464	50.465	50.466	50.467	50.468	50.469	50.470	50.471	50.472	50.473	50.474	50.475	50.476	50.477	50.478	50.479	50.480	50.481	50.482	50.483	50.484	50.485	50.486	50.487	50.488	50.489	50.490	50.491	50.492	50.493	50.494	50.495	50.496	50.497	50.498	50.499	50.500	50.501	50.502	50.503	50.504	50.505	50.506	50.507	50.508	50.509	50.510	50.511	50.512	50.513	50.514	50.515	50.516	50.517	50.518	50.519	50.520	50.521	50.522	50.523	50.524	50.525	50.526	50.527	50.528	50.529	50.530	50.531	50.532	50.533	50.534	50.535	50.536	50.537	50.538	50.539	50.540	50.541	50.542	50.543	50.544	50.545	50.546	50.547	50.548	50.549	50.550	50.551	50.552	50.553	50.554	50.555	50.556	50.557	50.558	50.559	50.560	50.561	50.562	50.563	50.564	50.565	50.566	50.567	50.568	50.569	50.570	50.571	50.572	50.573	50.574	50.575	50.576	50.577	50.578	50.579	50.580	50.581	50.582	50.583	50.584	50.585	50.586	50.587	50.588	50.589	50.590	50.591	50.592	50.593	50.594	50.595	50.596	50.597	50.598	50.599	50.600	50.601	50.602	50.603	50.604	50.605	50.606	50.607	50.608	50.609	50.610	50.611	50.612	50.613	50.614	50.615	50.616	50.617	50.618	50.619	50.620	50.621	50.622	50.623	50.624	50.625	50.626	50.627	50.628	50.

Table 29: Strength (kN) of Circular HSS Columns Filled with Bar-Reinforced Concrete Versus Time for Various Steel Outside Diameters, Steel Wall Thicknesses and Percentage Reinforcing Steel
 (Effective Length of Column: 2.5m, Concrete Strength: 35MPa, Concrete Cover: 50mm)

Table 30: Strength (kN) of Circular HSS Columns Filled with Bar-Reinforced Carbonate Concrete Versus Time for Various Steel Outside Diameters, Steel Wall Thicknesses and Percentage Reinforcing Steel
 (Effective Length of Column: 2.5m, Concrete Strength: 55MPa, Concrete Cover: 50mm)

Wall Thickness (mm)	Outside Diameter (mm)						Wall Thickness (mm)						Wall Thickness (mm)					
	219			273			324			386			406			427		
	4.8	5.1	5.6	6.1	6.7	7.2	7.8	8.4	9.0	9.6	10.2	10.8	11.4	12.0	12.7	13.4	14.0	
2.0	1825	2000	2404	2459	2570	2938	3104	3390	4298	4452	4735	4853	5107	6047	6267	6511	7051	8438
2.5	1444	1536	1772	1887	1976	2686	2834	3100	3824	3854	4206	4583	4829	5383	5876	6117	6828	8436
3.0	1011	1021	1113	1122	1135	2267	2417	2689	2987	3109	3275	4037	4273	4779	5632	5284	5776	8713
3.5	578	601	674	642	682	510	1954	2187	2201	2321	2466	3469	3708	4198	4167	4387	4881	5231
4.0	407	418	475	419	416	398	1489	1820	1849	1816	1749	3038	3239	3403	3400	3606	4087	4710
4.5	288	304	360	308	312	287	1214	1318	1519	1123	1286	1533	2728	2812	3007	2816	3098	3488
5.0	208	222	255	200	162	195	946	1022	1105	878	1020	1224	2334	2498	2489	2489	2641	3085
5.5	164	187	188	153	114	147	772	826	841	2020	2175	2476	2018	2121	2434	3808	3878	4439
6.0	128	133	158	61	90	112	656	702	788	542	604	786	1804	1930	2168	1705	1802	2036
6.5	94	100	116	86	90	102	556	591	668	447	490	653	1615	1722	1832	1473	1573	1761
7.0	74	77	91	65	68	79	475	507	567	582	582	1442	1524	1742	1284	1382	1521	
7.5	64	63	75	49	52	61	366	426	480	290	312	438	1285	1381	1563	1140	1209	1365
8.0	52	51	63	26	30	40	327	348	390	295	245	345	1166	1249	1407	998	1063	1197
8.5	44	44	44	44	44	44	44	44	44	44	44	44	1043	1107	1282	873	933	1053
9.0	39	39	39	39	39	39	39	39	39	39	39	39	925	985	1136	742	800	900
9.5	32	32	32	32	32	32	32	32	32	32	32	32	1453	1107	1282	737	837	934
10.0	27	27	27	27	27	27	27	27	27	27	27	27	822	875	1008	640	690	802
10.5	22	22	22	22	22	22	22	22	22	22	22	22	738	795	908	578	656	774
11.0	19	19	19	19	19	19	19	19	19	19	19	19	671	719	838	518	656	774
11.5	16	16	16	16	16	16	16	16	16	16	16	16	608	656	752	469	510	602
12.0	14	14	14	14	14	14	14	14	14	14	14	14	594	644	744	444	494	584
12.5	12	12	12	12	12	12	12	12	12	12	12	12	568	616	716	416	466	556
13.0	10	10	10	10	10	10	10	10	10	10	10	10	544	594	694	384	434	524
13.5	8	8	8	8	8	8	8	8	8	8	8	8	520	570	670	364	414	504
14.0	6	6	6	6	6	6	6	6	6	6	6	6	496	546	646	344	394	484
14.5	4	4	4	4	4	4	4	4	4	4	4	4	472	522	622	322	372	462
15.0	2	2	2	2	2	2	2	2	2	2	2	2	448	498	598	288	338	428
15.5	0	0	0	0	0	0	0	0	0	0	0	0	424	474	574	268	318	408
16.0	0	0	0	0	0	0	0	0	0	0	0	0	400	450	550	248	298	388
16.5	0	0	0	0	0	0	0	0	0	0	0	0	376	426	526	228	278	368
17.0	0	0	0	0	0	0	0	0	0	0	0	0	352	402	502	208	258	348
17.5	0	0	0	0	0	0	0	0	0	0	0	0	328	378	478	188	238	328
18.0	0	0	0	0	0	0	0	0	0	0	0	0	304	354	454	164	214	304
18.5	0	0	0	0	0	0	0	0	0	0	0	0	280	330	430	140	190	280
19.0	0	0	0	0	0	0	0	0	0	0	0	0	256	306	406	116	166	256
19.5	0	0	0	0	0	0	0	0	0	0	0	0	232	282	382	96	146	236
20.0	0	0	0	0	0	0	0	0	0	0	0	0	208	258	358	76	126	216
20.5	0	0	0	0	0	0	0	0	0	0	0	0	184	234	334	56	106	196
21.0	0	0	0	0	0	0	0	0	0	0	0	0	160	210	310	32	82	172
21.5	0	0	0	0	0	0	0	0	0	0	0	0	136	186	286	12	62	152
22.0	0	0	0	0	0	0	0	0	0	0	0	0	112	162	262	0	50	140
22.5	0	0	0	0	0	0	0	0	0	0	0	0	88	138	238	0	38	128
23.0	0	0	0	0	0	0	0	0	0	0	0	0	64	114	214	0	28	118
23.5	0	0	0	0	0	0	0	0	0	0	0	0	40	90	190	0	18	108
24.0	0	0	0	0	0	0	0	0	0	0	0	0	16	66	166	0	8	98
24.5	0	0	0	0	0	0	0	0	0	0	0	0	8	44	144	0	4	104
25.0	0	0	0	0	0	0	0	0	0	0	0	0	4	22	122	0	2	102
25.5	0	0	0	0	0	0	0	0	0	0	0	0	2	11	111	0	1	101
26.0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	11	0	0	100
26.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
27.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
27.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
28.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
28.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
29.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
29.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
30.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
30.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
31.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
31.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
32.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
32.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
33.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
33.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
34.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
34.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
35.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
35.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
36.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
36.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
37.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
37.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
38.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
38.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
39.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
39.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
40.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
40.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
41.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
41.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
42.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
42.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
43.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
43.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
44.0	0	0	0</td															

Table 31: Strength (kN) of Circular HSS Columns Filled with Bar-Reinforced Carbonate Concrete Versus Time for Various Steel Outside Diameters, Steel Wall Thicknesses and Percentage Reinforcing Steel
 (Effective Length of Column: 3.0m, Concrete Strength: 20MPa, Concrete Cover: 50mm)

**Table 32: Strength (kN) of Circular HSS Columns Filled with Bar-Reinforced Carbonate Concrete Versus Time for Various Steel Outside Diameters, Steel Wall Thicknesses and Percentage Reinforcing Steel
(Effective Length of Column: 3.0m, Concrete Strength: 35MPa, Concrete Cover: 50mm)**

Time (hr)	Outside Diameter (mm)										Outside Diameter (mm)									
	168					210					273					324				
	% Steel	Wall Thickness (mm)	Wall Thickness (mm)	Wall Thickness (mm)	% Steel	% Steel	Wall Thickness (mm)	Wall Thickness (mm)	Wall Thickness (mm)	% Steel	% Steel	Wall Thickness (mm)	Wall Thickness (mm)	Wall Thickness (mm)	% Steel	% Steel	Wall Thickness (mm)	Wall Thickness (mm)	Wall Thickness (mm)	% Steel
0.0	2.0	2.5	3.1	2.3	2.9	5.7	1.2	2.6	5.2	1.4	3.0	6.1	1.3	2.6	6.6	1.5	2.9	6.2	1.6	3.2
1	1408	1433	1673	2004	2036	2170	2224	2380	2648	3008	3170	4038	3740	3973	4495	5195	5435	5850	6128	5404
10	680	686	870	1428	1488	1492	1883	2013	2236	3048	3172	3854	4158	4734	4958	5453	4842	5116	5787	6151
20	252	456	413	772	778	781	1459	1588	1781	2011	2066	2131	2872	3103	3817	4075	4875	4224	4490	5172
30	248	218	287	423	421	416	1079	1309	1311	1959	1141	2583	2576	3070	2988	3239	3796	3680	3826	4891
40	198	187	243	262	259	267	849	993	1156	852	911	911	1989	2168	2153	2837	2588	3105	3198	3480
50	124	130	179	196	196	147	866	798	953	659	574	802	1702	1877	1923	2137	2595	2901	3181	3768
60	98	98	129	122	124	106	483	611	746	481	460	642	1578	1549	1902	1583	1726	2123	2563	2840
70	68	76	101	94	96	84	400	507	630	588	620	1180	1274	1566	1158	1284	1591	2238	2481	3021
80	53	58	80	72	48	85	329	412	536	249	307	425	987	1082	1330	913	1016	1206	2036	2261
90	50	43	60	34	56	68	270	338	456	168	256	363	863	938	1188	769	868	1111	1843	2038
100	50	50	53	49	27	42	48	224	279	363	142	217	306	768	819	1080	656	738	955	1682
110	41	25	28	41	30	31	38	177	254	321	119	177	229	331	119	177	229	331	1719	2085
120	20	20	23	36	20	22	24	151	187	292	105	149	212	594	658	827	557	731	1426	1924
130	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
140	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
150	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
160	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
170	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
180	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
190	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
200	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
210	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
220	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
230	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
240	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
250	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
260	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
270	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
280	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
290	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
300	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
310	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
320	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
330	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
340	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
350	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
360	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
370	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
380	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
390	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
400	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
410	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
420	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
430	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
440	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
450	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
460	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
470	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
480	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
490	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
500	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
510	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
520	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
530	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
540	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
550	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
560	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
570	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
580	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
590	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
600	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
610	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
620	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
630	10	10	10																	

Table 33: Strength (kN) of Circular HSS Columns Filled with Bar-Reinforced Carbonate Concrete Versus Time for Various Steel Outside Diameters, Steel Wall Thicknesses and Percentage Reinforcing Steel
 (Effective Length of Column: 3.0m, Concrete Strength: 55MPa, Concrete Cover: 50mm)

Steel Pipe Properties															
Outer Diameter (mm)	Wall Thicknesses (mm)								Wall Thicknesses (mm)						
	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.4	6.8	7.2	7.6	8.0	8.4
168	4.8	9.5	14.2	18.9	22.6	26.3	30.0	33.7	37.4	41.1	44.8	48.5	52.2	55.9	59.6
172	5.1	9.6	14.3	19.0	22.7	26.4	30.1	33.8	37.5	41.2	44.9	48.6	52.3	56.0	59.7
176	5.4	9.8	14.5	19.2	22.9	26.6	30.3	34.0	37.7	41.4	45.1	48.8	52.5	56.2	60.0
180	5.7	10.0	14.7	19.4	23.1	26.8	30.5	34.2	37.9	41.6	45.3	49.0	52.7	56.4	60.2
184	6.0	10.2	14.9	19.6	23.3	27.0	30.7	34.4	38.1	41.8	45.5	49.2	52.9	56.6	60.4
188	6.3	10.4	15.1	19.8	23.5	27.2	30.9	35.1	38.8	42.5	46.2	49.9	53.6	57.3	61.1
192	6.6	10.6	15.3	19.9	23.7	27.4	31.1	35.3	39.0	42.7	46.4	50.1	53.8	57.5	61.3
196	6.9	10.8	15.5	20.1	23.9	27.6	31.3	35.5	39.2	42.9	46.6	50.3	54.0	57.7	61.5
200	7.2	11.0	15.7	20.3	24.1	27.8	31.5	35.7	39.4	43.1	46.8	50.5	54.2	57.9	61.7
204	7.5	11.2	15.9	20.5	24.3	28.0	31.7	35.9	39.6	42.8	47.5	51.2	54.9	58.6	62.4
208	7.8	11.4	16.1	20.7	24.5	28.2	31.9	36.1	39.8	43.5	48.2	51.9	55.6	59.3	63.1
212	8.1	11.6	16.3	20.9	24.7	28.4	32.1	36.3	40.0	43.7	48.4	52.1	55.8	59.5	63.3
216	8.4	11.8	16.5	21.1	24.9	28.6	32.3	36.5	40.2	44.0	48.7	52.4	56.1	59.8	63.6
220	8.7	12.0	16.7	21.3	25.1	28.8	32.5	36.7	40.4	44.2	48.9	52.6	56.3	60.0	63.8
224	9.0	12.2	16.9	21.5	25.3	29.0	32.7	36.9	40.6	44.4	49.1	52.8	56.5	60.2	64.0
228	9.3	12.4	17.1	21.7	25.5	29.2	32.9	37.1	40.8	44.6	49.3	53.0	56.7	60.4	64.2
232	9.6	12.6	17.3	21.9	25.7	29.4	33.1	37.3	41.0	44.8	49.5	53.2	56.9	60.6	64.4
236	9.9	12.8	17.5	22.1	25.9	29.6	33.3	37.5	41.2	45.0	49.7	53.4	57.1	60.8	64.6
240	10.2	13.0	17.7	22.3	26.1	29.8	33.5	37.7	41.4	45.2	49.9	53.6	57.3	61.0	64.8
244	10.5	13.2	17.9	22.5	26.3	29.9	33.7	37.9	41.6	45.4	49.9	53.8	57.5	61.2	65.0
248	10.8	13.4	18.1	22.7	26.5	30.1	33.9	38.1	41.8	45.6	49.9	54.0	57.7	61.4	65.2
252	11.1	13.6	18.3	22.9	26.7	30.3	34.1	38.3	42.0	45.8	49.9	54.2	57.9	61.6	65.4
256	11.4	13.8	18.5	23.1	26.9	30.5	34.3	38.5	42.2	46.0	49.9	54.4	58.1	61.8	65.6
260	11.7	14.0	18.7	23.3	27.1	30.7	34.5	38.7	42.4	46.2	49.9	54.6	58.3	62.0	65.8
264	12.0	14.2	18.9	23.5	27.3	30.9	34.7	38.9	42.6	46.4	49.9	54.8	58.5	62.2	66.0
268	12.3	14.4	19.1	23.7	27.5	31.1	34.9	39.1	42.8	46.6	49.9	55.0	58.7	62.4	66.2
272	12.6	14.6	19.3	23.9	27.7	31.3	35.1	39.3	43.0	46.8	49.9	55.2	59.0	62.6	66.4
276	12.9	14.8	19.5	24.1	27.9	31.5	35.3	39.5	43.2	47.0	49.9	55.4	59.2	62.8	66.6
280	13.2	15.0	19.7	24.3	28.1	31.7	35.5	39.7	43.4	47.2	49.9	55.6	59.4	63.0	66.8
284	13.5	15.2	19.9	24.5	28.3	31.9	35.7	39.9	43.6	47.4	49.9	55.8	59.6	63.2	67.0
288	13.8	15.4	20.1	24.7	28.5	32.1	35.9	40.1	43.8	47.6	49.9	56.0	59.8	63.4	67.2
292	14.1	15.6	20.3	24.9	28.7	32.3	36.1	40.3	44.0	47.8	49.9	56.2	59.8	63.6	67.4
296	14.4	15.8	20.5	25.1	28.9	32.5	36.3	40.5	44.2	48.0	49.9	56.4	59.8	63.8	67.6
300	14.7	16.0	20.7	25.3	29.1	32.7	36.5	40.7	44.4	48.2	49.9	56.6	59.8	64.0	67.8
304	15.0	16.2	20.9	25.5	29.3	32.9	36.7	40.9	44.6	48.4	49.9	56.8	59.8	64.2	68.0
308	15.3	16.4	21.1	25.7	29.5	33.1	36.9	41.1	44.8	48.6	49.9	57.0	59.8	64.4	68.2
312	15.6	16.6	21.3	25.9	29.7	33.3	37.1	41.3	45.0	48.8	49.9	57.2	59.8	64.6	68.4
316	15.9	16.8	21.5	26.1	29.9	33.5	37.3	41.5	45.2	49.0	49.9	57.4	59.8	64.8	68.6
320	16.2	17.0	21.7	26.3	30.1	33.7	37.5	41.7	45.4	49.2	49.9	57.6	59.8	65.0	68.8
324	16.5	17.2	21.9	26.5	30.3	33.9	37.7	41.9	45.6	49.4	49.9	57.8	59.8	65.2	69.0
328	16.8	17.4	22.1	26.7	30.5	34.1	37.9	42.1	45.8	49.6	49.9	58.0	59.8	65.4	69.2
332	17.1	17.6	22.3	26.9	30.7	34.3	38.1	42.3	46.0	49.8	49.9	58.2	59.8	65.6	69.4
336	17.4	17.8	22.5	27.1	30.9	34.5	38.3	42.5	46.2	49.9	49.9	58.4	59.8	65.8	69.6
340	17.7	18.0	22.7	27.3	31.1	34.7	38.5	42.7	46.4	49.9	49.9	58.6	59.8	66.0	69.8
344	18.0	18.2	22.9	27.5	31.3	34.9	38.7	42.9	46.6	49.9	49.9	58.8	59.8	66.2	70.0
348	18.3	18.4	23.1	27.7	31.5	35.1	38.9	43.1	46.8	49.9	49.9	59.0	59.8	66.4	70.2
352	18.6	18.6	23.3	27.9	31.7	35.3	39.1	43.3	47.0	49.9	49.9	59.2	59.8	66.6	70.4
356	18.9	18.8	23.5	28.1	31.9	35.5	39.3	43.5	47.2	49.9	49.9	59.4	59.8	66.8	70.6
360	19.2	19.0	23.7	28.3	32.1	35.7	39.5	43.7	47.4	49.9	49.9	59.6	59.8	67.0	70.8
364	19.5	19.2	23.9	28.5	32.3	35.9	39.7	43.9	47.6	49.9	49.9	59.8	59.8	67.2	71.0
368	19.8	19.4	24.1	28.7	32.5	36.1	39.9	44.1	47.8	49.9	49.9	59.8	59.8	67.4	71.2
372	20.1	19.6	24.3	28.9	32.7	36.3	40.1	44.3	48.0	49.9	49.9	59.8	59.8	67.6	71.4
376	20.4	19.8	24.5	29.1	32.9	36.5	40.3	44.5	48.2	49.9	49.9	59.8	59.8	67.8	71.6
380	20.7	20.0	24.7	29.3	33.1	36.7	40.5	44.7	48.4	49.9	49.9	59.8	59.8	68.0	71.8
384	21.0	20.2	24.9	29.5	33.3	36.9	40.7	44.9	48.6	49.9	49.9	59.8	59.8	68.2	72.0
388	21.3	20.4	25.1	29.7	33.5	37.1	40.9	45.1	48.8	49.9	49.9	59.8	59.8	68.4	72.2
392	21.6	20.6	25.3	29.9	33.7	37.3	41.1	45.3	49.0	49.9	49.9	59.8	59.8	68.6	72.4
396	21.9	20.8	25.5	30.1	33.9	37.5	41.3	45.5	49.2	49.9	49.9	59.8	59.8	68.8	72.6
400	22.2	21.0	25.7	30.3	34.1	37.7	41.5	45.7	49.4	49.9	49.9	59.8	59.8	69.0	72.8
404	22.5	21.2	25.9	30.5	34.3	37.9	41.7	45.9	49.6	49.9	49.9	59.8	59.8	69.2	73.0
408	22.8	21.4	26.1	30.7	34.5	38.1	41.9	46.1	49.8	49.9	49.9	59.8	59.8	69.4	73.2
412	23.1	21.6	26.3	30.9	34.7	38.3	42.1	46.3	50.0	49.9	49.9	59.8	59.8	69.6	73.4
416	23.4	21.8	26.5	31.1	34.9	38.5	42.3	46.5	50.2	49.9	49.9	59.8	59.8	69.8	73.6
420	23.7	22.0	26.7	31.3	35.1	38.7	42.5	46.7	50.4	49.9	49.9	59.8	59.8	70.0	73.8
424	24.0	22.2	26.9	31.5	35.3	38.9	42.7	46.9	50.6	49.9	49.9	59.8	59.8	70.2	74.0
428	24.3	22.4	27.1	31.7	35.5	39.1	42.9	47.1	50.8	49.9	49.9	59.8	59.8	70.4	74.2
432	24.6	22.6	27.3	31.9	35.7	39.3	43.1	47.3	51.0	49.9	49.9	59.8	59.8	70.6	74.4
436	24.9	22.8	27.5	32.1	35.9	39.5	43.3	47.5	51.2	49.9	49.9	59.8	59.8	70.8	74.6
440	25.2	23.0	27.7	32.3	36.1	39.7	43.5	47.7	51.4	49.9	49.9	59.8	59.8	71.0	74.8
444	25.5	23.2	27.9	32.5	36.3	39.9	43.7	47.9	51.6	49.9	49.9	59.8	59.8	71.2	75.0
448	25.8	23.4	28.1	32.7	36.5	40.1	43.9	48.1	51.8	49.9	49.9	59.8	59.8	71.4	75.2
452	26.1	23.6	28.3	32.9	36.7	40.3	44.1	48.3	52.0	49.9	49.9	59.8	59.8	71.6	75.4
456	26.4	23.8	28.5	33.1	36.9	40.5	44.3	48.5	52.2	49.9	49.9	59.8	59.8	71.8	75.6
460	26.7	24.0	28.7	33.3	37.1	40.7	44.5	48.7	52.4	49.9	49.9	59.8	59.8	72.0	75.8
464	27.0	24.2	28.9	33.5	37.3	40.9	44.7	48.9	52.6	49.9	49.9	59.8	59.8	72.2	76.0
468	27.3	24.4	29.1	33.7	37.5	41.1	44.9	49.1	52.8	49.9	49.9	59.8	59.8	72.4	76.2
472	27.6	24.6	29.3	33.9	37.7	41.3	45.1	49.3	53.0	49.9	49.9	59.8	59.8	72.6	76.4
476	27.9	24.8	29.5	34.1	37.9	41.5	45.3	49.5	53.2	49.9	49.9	59.8	59.8	72.8	76.6
480	28.2	25.0	29.7	34.3	38.1	41.7	45.5	49.7	53.4						

Table 34: Strength (kN) of Circular HSS Columns Filled with Bar-Reinforced Carbonate Concrete Versus Time for Various Steel Outside Diameters, Steel Wall Thicknesses and Percentage Reinforcing Steel
 (Effective Length of Column: 4.5m, Concrete Strength: 20MPa, Concrete Cover: 50mm)

**Table 35: Strength (kN) of Circular HSS Columns Filled with Bar-Reinforced Carbonate Concrete Versus Time for Various Steel Outside Diameters, Steel Wall Thicknesses and Percentage Reinforcing Steel
(Effective Length of Column: 4.5m, Concrete Strength: 35MPa, Concrete Cover: 50mm)**

Time (min)	Outside Diameter (mm)												Wall Thickness (mm)																							
	168						219						273						324						408											
	Wall Thickness (mm)	% Steel	Wall Thickness (mm)	% Steel	Wall Thickness (mm)	% Steel	Wall Thickness (mm)	% Steel	Wall Thickness (mm)	% Steel	Wall Thickness (mm)	% Steel	Wall Thickness (mm)	% Steel	Wall Thickness (mm)	% Steel	Wall Thickness (mm)	% Steel	Wall Thickness (mm)	% Steel	Wall Thickness (mm)	% Steel	Wall Thickness (mm)	% Steel	Wall Thickness (mm)	% Steel	Wall Thickness (mm)	% Steel								
0	2.0	4.8	9.5	4.8	12.7	6.4	12.7	6.4	12.7	6.4	12.7	6.4	12.7	6.4	12.7	6.4	12.7	6.4	12.7	6.4	12.7	6.4	12.7	6.4	12.7	6.4	12.7									
10	1217	1217	1280	1856	1917	1874	2111	2341	2277	3417	3648	3395	3606	4078	4754	4947	5427	4754	4945	5638	6446	6708	7319	5578	6027	6798	7466	7951	8734	7200	7773	8856	9434	9886	11161	
20	613	515	526	1058	1049	1010	1268	1338	1412	2366	2423	2508	2860	3286	3900	4052	4585	4274	4556	5267	5673	5888	6594	6192	5683	6441	6846	7342	8121	8535	7397	8578	8875	9448	10619	
30	216	217	126	546	509	409	908	1278	1303	1318	2055	2230	2506	2413	1799	2775	3576	3821	4584	4442	4656	5300	4443	4946	5750	5631	6213	7082	8042	6807	7781	7842	8229	9459		
40	239	60	118	259	233	233	297	417	501	743	718	721	1596	1743	2138	1512	1559	1687	2973	3287	4038	3506	3741	4416	5780	4266	4611	5197	6045	5306	5895	7026	6515	7112	8207	
50	145	44	103	135	125	125	108	342	456	438	420	475	1406	1607	987	515	1390	2461	2827	3548	2806	3057	3726	5196	3660	4382	3802	4339	5102	4757	5302	6413	5580	6142	7283	
60	31	44	76	94	100	82	115	299	369	313	344	218	803	1080	1621	737	793	1200	2035	2511	3184	2373	2827	3317	3688	3391	3955	3271	3745	4715	4916	4855	5914	4847	5363	6443
70	26	39	56	39	59	46	155	236	315	222	132	264	678	900	1273	564	687	1052	1776	2196	2818	2080	2335	3019	2494	2817	3883	2747	3080	3890	3871	4443	5509	4431	4896	5988
80	25	30	42	80	25	35	128	202	284	309	86	217	678	739	1061	370	675	891	1432	1797	2309	1701	1940	2506	2143	2453	2915	2237	2532	3011	3491	3906	4814	3897	4130	5083
90	20	23	39	20	20	28	106	189	225	106	112	179	489	618	914	352	484	761	1136	1530	1983	1324	1538	2044	1895	2108	2440	1854	1982	2402	3241	4535	3275	3656	4581	
100	15	17	25	57	19	21	92	142	183	235	99	149	425	644	814	298	432	870	1295	1684	1059	1258	1731	1720	1886	2179	1597	1695	2082	2874	3298	4057	2899	3226	3969	
110	12	14	20	10	12	17	77	122	165	206	82	126	382	487	724	285	391	900	1137	1483	904	1096	1504	1526	1609	1926	1317	1445	1793	2752	3050	3713	2620	2810	3542	
120	10	11	17	9	9	15	66	104	142	42	66	105	316	415	646	243	360	554	707	989	1326	1395	1932	1743	1749	1279	1148	1279	1589	2547	2835	3443	3293	3973	3250	
130	6	9	16	6	7	10	66	121	55	67	86	121	273	571	684	216	314	496	652	688	1209	880	904	1171	1232	1286	1587	1029	1140	1444	2365	2815	3111	3186	2416	2982
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Table 36: Strength (kN) of Circular HSS Columns Filled with Bar-Reinforced Carbonate Concrete Versus Time for Various Steel Outside Diameters, Steel Wall Thicknesses and Percentage Reinforcing Steel
 (Effective Length of Column: 4.5m, Concrete Strength: 55MPa, Concrete Cover: 50mm)

APPENDIX**MATERIAL PROPERTIES AND SPECIFICS OF COLUMNS**

The values of the material properties used in this study are given in Reference 3 and are the same as those used in Reference 1 for the calculation of the fire resistance of concrete filled steel columns.

STEEL PROPERTIES**Stress-strain relations**

for $\epsilon_s \leq \epsilon_p$

$$f_s = \frac{f(T, 0.001)}{0.001} \epsilon_s$$

for $\epsilon_s > \epsilon_p$

$$f_s = \frac{f(T, 0.001)}{0.001} \epsilon_p + f(T, (\epsilon_s - \epsilon_p + 0.001)) - f(T, 0.001)$$

where

$$\epsilon_p = 4 \times 10^{-6} f_{y0}$$

$$f(T, \epsilon_s) = (50 - 0.04T) [1 - \text{Exp}((-30 + 0.03T)\sqrt{\epsilon_s})] \times 6.9$$

Thermal capacity

for $0 \leq T \leq 650^\circ\text{C}$

$$\rho_s c_s = (0.004T + 3.3) \times 10^6$$

for $725 < T \leq 800^\circ\text{C}$

$$\rho_s c_s = (-0.068T + 38.30) \times 10^6$$

for $725 < T \leq 800^\circ\text{C}$

$$\rho_s c_s = (-0.086T + 73.35) \times 10^6$$

for $T > 800^\circ\text{C}$

$$\rho_s c_s = 4.55 \times 10^6$$

Thermal conductivityfor $0 \leq T \leq 900^\circ\text{C}$

$$k_s = (-0.022T + 48)$$

for $T > 900^\circ\text{C}$

$$k_s = 28.20$$

Coefficient of thermal expansionfor $T < 1000^\circ\text{C}$

$$\alpha_s = (0.004T + 12) \times 10^{-6}$$

for $T \geq 1000^\circ\text{C}$

$$\alpha_s = 16 \times 10^{-6}$$

CONCRETE PROPERTIES**Stress-strain relations**for $\varepsilon_c \leq \varepsilon_{\max}$

$$f_c' = f_c' \left[1 - \left(\frac{\varepsilon_{\max} - \varepsilon_c}{\varepsilon_{\max}} \right)^2 \right]$$

for $\varepsilon_c > \varepsilon_{\max}$

$$f_c' = f_c' \left[1 - \left(\frac{\varepsilon_c - \varepsilon_{\max}}{3\varepsilon_{\max}} \right)^2 \right]$$

where

$$\varepsilon_{\max} = 0.0025 + (6.0T + 0.04T^2) \times 10^{-6}$$

if $T < 450^\circ\text{C}$

$$f_c' = f_{c0}'$$

if $T \geq 450^\circ\text{C}$

$$f_c' = f_{c0}' \left[2.011 - 2.353 \left(\frac{T-20}{1000} \right) \right]$$

Thermal capacity**Siliceous Aggregate Concrete**for $0 \leq T \leq 200^\circ\text{C}$

$$\rho_{cCc} = (0.005T + 1.7) \times 10^6$$

for $200^\circ\text{C} < T \leq 400^\circ\text{C}$

$$\rho_{cCc} = 2.7 \times 10^6$$

for $400^\circ\text{C} < T \leq 500^\circ\text{C}$

$$\rho_{cCc} = (0.013T - 2.5) \times 10^6$$

for $500^\circ\text{C} < T \leq 600^\circ\text{C}$

$$\rho_{cCc} = (-0.013T + 10.5) \times 10^6$$

for $T > 600^\circ\text{C}$

$$\rho_{cCc} = 2.7 \times 10^6$$

Carbonate Aggregate Concretefor $0 \leq T \leq 400^\circ\text{C}$

$$\rho_{cCc} = 2.566 \times 10^6$$

for $400^\circ\text{C} < T \leq 410^\circ\text{C}$

$$\rho_{cCc} = (0.1765T - 68.034) \times 10^6$$

for $410^\circ\text{C} < T \leq 445^\circ\text{C}$

$$\rho_{cCc} = (-0.05043T + 25.00671) \times 10^6$$

for $445^\circ\text{C} < T \leq 500^\circ\text{C}$

$$\rho_{cCc} = 2.566 \times 10^6$$

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for $500^{\circ}\text{C} < T \leq 635^{\circ}\text{C}$

$$\rho_{cc_c} = (0.01603T - 5.44881) \times 10^6$$

for $635^{\circ}\text{C} < T \leq 715^{\circ}\text{C}$

$$\rho_{cc_c} = (0.016635T - 100.90225) \times 10^6$$

for $715^{\circ}\text{C} < T \leq 785^{\circ}\text{C}$

$$\rho_{cc_c} = (-0.22103T + 176.07343) \times 10^6$$

for $T > 785^{\circ}\text{C}$

$$\rho_{cc_c} = 2.566 \times 10^6$$

Thermal conductivity

Siliceous Aggregate Concrete

for $0 \leq T \leq 800^{\circ}\text{C}$

$$k_c = (-0.00085T + 1.9)$$

for $T > 800^{\circ}\text{C}$

$$k_c = 1.22$$

Carbonate Aggregate Concrete

for $0 \leq T \leq 293^{\circ}\text{C}$

$$k_s = 1.355$$

for $T > 293^{\circ}\text{C}$

$$k_s = -0.00124T + 1.7162$$

Coefficient of thermal expansion

$$\alpha_s = (0.008T + 6) \times 10^{-6}$$

WATER PROPERTIES

Thermal capacity

$$\rho_w c_w = 4.2 \times 10^6$$

Heat of vaporization

$$\lambda_w = 2.3 \times 10^6$$

SPECIFICS OF COLUMN AND FIRE

ϵ_f = emissivity of fire: 0.75

ϵ_s = emissivity of steel: 0.8

ϕ = concentration of moisture in concrete by volume: 0.10