Engineering Journal issn: 0125-8281

Article

Comparative Structural Design for Pressure- and Temperature- Resistant Buildings with Loads Affecting Externally on Structures of Different Heights

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Abstract. Loads from explosions can be classified as internal blast load and external blast load and these loads have great severity, continuity and rapidity. That is, explosions cause massive structural damage by exposing surrounding structures to extremely high pressure and temperature. Thus, structures at risk of explosive damage must be stronger than typical buildings in withstanding both ordinary loads and the additional pressure and temperature loads caused. Explosion-resistant structures are required in the petrochemical industry, explosive armories, power stations, and gas storage facilities, among others. This study aims to examine and compare the structural performance of two building of different heights, which are 5-floor and 2-floor, subject to three types of loads: (1) the pressure of 300 bars, (2) the temperature of 300 °C, and (3) the pressure of 300 bars combined with the temperature of 300 °C. The research analyzes three primary reinforced structures, namely columns, beams, and slabs, in terms of the parameters resulting from each scenario to determine a set of criteria for designing the structural components of the buildings to resist the external blasts.

Keywords: External pressure load, external temperature load, pressure- and temperature-resistant buildings.

ENGINEERING JOURNAL Volume 23 Issue 3
Received 16 November 2018
Accepted 19 March 2019
Published 31 May 2019
Online at http://www.engj.org/
DOI:10.4186/ej.2019.23.3.95

DOI:10.4186/ej.2019.23.3.95

1. Introduction

Designing residential buildings in Thailand generally involves the utilization of space and aesthetics as well as fulfilment of the standards and requirements stipulated in the 2522 B.E. Building Control Act. However, some structures at risk of explosions, such as buildings in the petrochemical industry [1], explosive armories[2], power stations[3-4], gas storage facilities[1, 5], and energy research centres[6], must also be designed to resist the additional loads resulting from explosive pressure[7] and temperature[8], to prevent collapse, and ultimately to safeguard life and property. To this end, their design must account for not only dead loads (DLs) [9-12] and live loads (LLs) [9-12], but also blast load (BLs) [13]. Since BLs [13] consist of pressure loads, temperature loads, and combined pressure and temperature loads, they are more severe and occur in exponentially smaller time-windows than either seismic or seasonal wind loads.
[14-15].

This study focuses on designing explosion-resistant buildings [1] that can ensure the safety of life and property. Its results will provide guidelines for designing constructions susceptible to explosions. The three primary structures under study, namely columns, beams, and slabs, form the structural components of a building prototype designed for the petrochemical industry where the mixing of gases, such as N_2, H_2, H_2S, CO_2, O_2, LPG, LNG, and He, takes place. The building houses the common processes and equipment shown in Fig. 1.1.

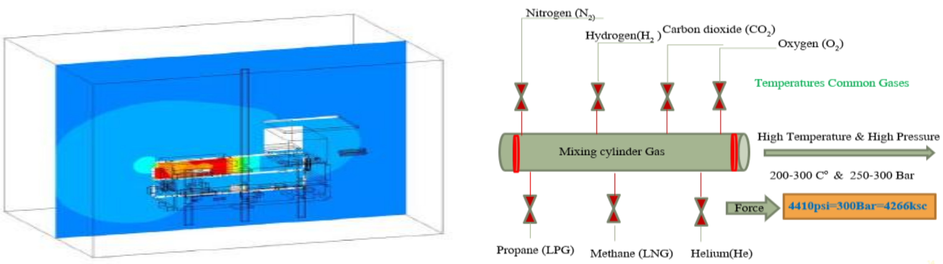


Fig. 1.1. Gas mixing cylinder.

With regards to the characteristics of potential explosions in the building, the pressure travels from the bottom to the top and decreases gradually. In addition, the radius of explosions becomes larger, as shown in Fig. 1.2.

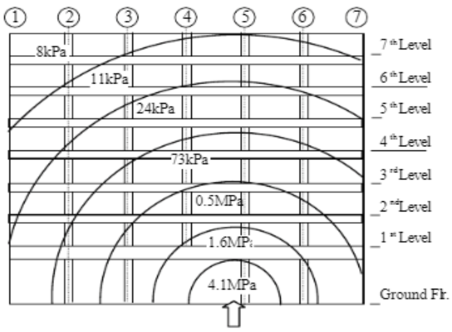


Fig. 1.2. Internal blasts [16].

The pattern of explosive loads is a high and complex pressure expanding in every direction consisting of the pressure from blast waves and reflected waves. Therefore, wall ventilators installed in the construction can reduce severity rates from blasts, as shown in Fig. 1.3 [1, 17].

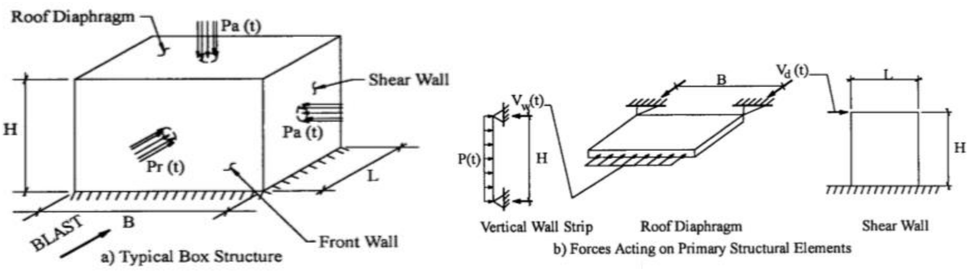


Fig. 1.3. Effects of ventilators on internal blasts [1].

Outside of the building sits the equipment used for gas storage and high-pressure control, as shown in Fig. 1.4. This area is designated as a hazardous or safety alert zone [18].

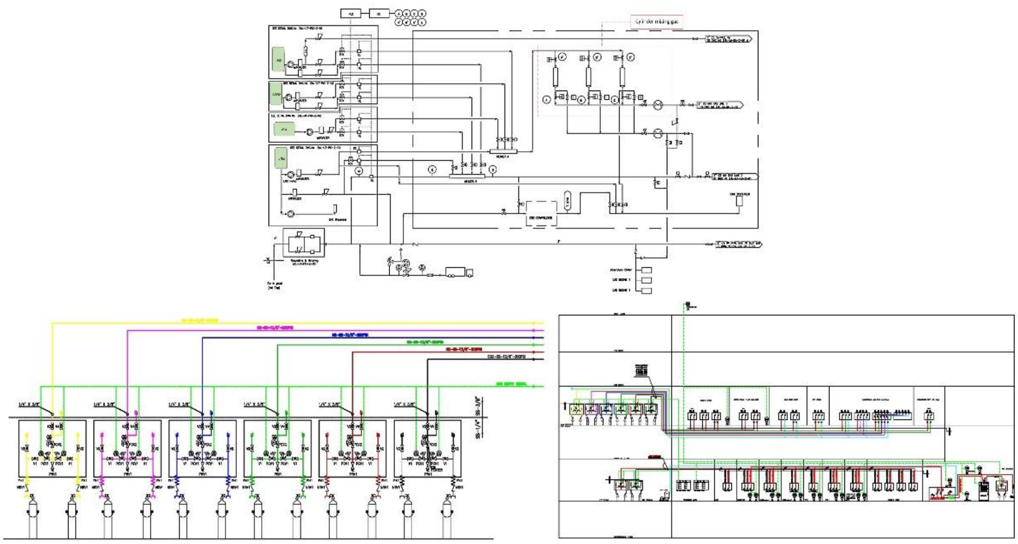


Fig. 1.4. Equipment installed outside the building.

Explosive severity depends on the distance from the sources of blasts, as shown in Fig. 1.5 [5, 19].

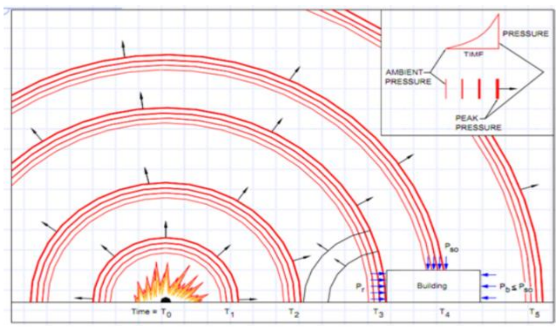


Fig. 1.5. Externals blasts [5].

Figure 1.5 shows the characteristics of external blasts and pressure wave expansion. To determine the scaled distance (Z), the following equation is used [16]:

$$Z = R/W^{1/3} \tag{1}$$

$Z > 10$ *Far Field Blast*

$3 < Z < 10 \quad Near\ Field\ Blast$
$Z < 3 \quad Close - in\ Blast$
$W = Mass\ of\ the\ explosion$
$R = Distance\ from\ the\ detonation\ source$

Table 1.1. Ratio of explosive mass to distance from the detonation source [16].

R \ W	100 kg TNT	500 kg TNT	1000 kg TNT	2000 kg TNT
1m	165.8	354.5	464.5	602.9
2.5m	34.2	89.4	130.8	188.4
5 m	6.65	24.8	39.5	60.19
10m	0.85	4.25	8.15	14.7
15m	0.27	1.25	2.53	5.01
20m	0.14	0.54	1.06	2.13
25m	0.09	0.29	0.55	1.08
30m	0.06	0.19	0.33	0.63

The pressure caused by explosions will flow up through the atmosphere until reaching a peak P_{so}, referred to as the positive phase, and will then flow back through the atmosphere to the point underneath it $-P_{so}$, referred to as the negative phase, as shown in Fig. 1.6 [1]. This cycle will repeat until there is no pressure left.

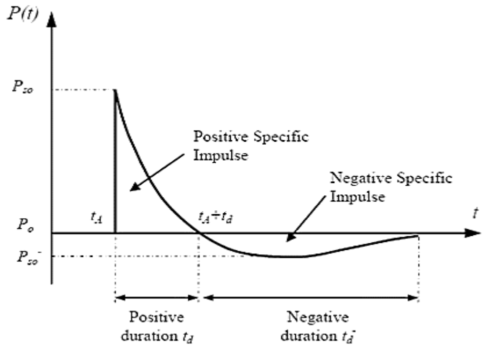


Fig. 1.6. Relationships between explosive duration and pressure [1, 20].

$$I_0 = \int_0^{td} P(t)dt \tag{2}$$

$$= 0.5P_{so}t_d, for\ a\ triangular\ wave$$
$$= 0.64P_{so}t_d, for\ a\ half - sine\ wave$$
$$= cP_{so}t_d, for\ an\ exponentially\ decaying\ shock\ wave$$

Where:
$I_0 = Phase\ Impulse$
$P(t) = Overpressure\ function\ with\ respect\ to\ time$
$P_{so} = Peak, or\ incident, side - on\ overpressure$
$t_d = Duration\ of\ the\ positive\ phase$
$c = A\ value\ between\ 0.2\ and\ 0.5\ depending\ on\ P_{so}$

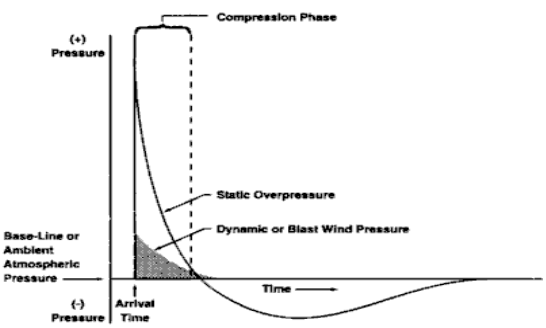


Fig. 1.7. Relationships between the negative phase and vibration waves [1, 20].

Before the negative phase, the pressure increases, and the compressed air causes a shockwave. During this period, the pressure is a dynamic waveform expanding in a circular pattern. The wave characterizing an explosion is referred to as a shock load, which is a vibration wave [20].

Since fuel is a high-temperature hydrocarbon affecting the strength requirements of a building, the structural components of the construction need to be considered in conjunction with the temperature generated from the combustion of a blast. The thermal resistance characteristics of steel and concrete are shown in Table 1.2.

Table 1.2. Comparison of the strength of concrete and steel.

Properties	Mild Steel	Concrete
Mass per unit kg (m^3)	7850	2400
Elastic modulus (ksc)	2100000	200000
Thermal resistance (°C)	250-550	300-600
Lifespan (y)	10-20	30-50
Compressive strength (ksc)	3500-5000	200-500
Tensile strength (ksc)	3500-5000	0-50

Table 1.2 shows that steel is less resistant to heat than concrete, whereas concrete is less resistant to strain than steel. The relationships between temperature and steel strength are shown in Fig. 1.8 [21].

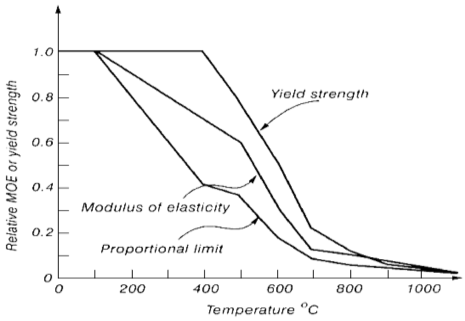


Fig. 1.8. Relationships between temperature and steel strength [21].

For concrete, a rise in temperature will decrease its strength, as shown in Fig. 1.9. As the temperature rises, concrete will expand, which in turn increases its strain percentage and lowers its strength, causing the material to collapse [21].

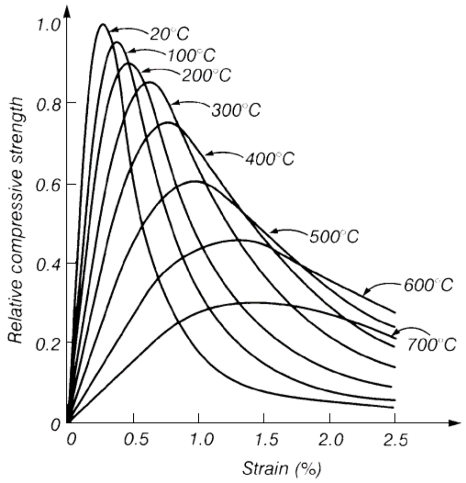


Fig. 1.9. Relationships between temperature and strain percentage [21].

2. Comparative Design for 5-floor and 2-floor Buildings Which Can Resist the External Pressure Load of 300 Bars

Figure 2.1 shows the models of two test buildings, whose heights are 5 floors and 2 floors with dimensions of 40.00 m x 30.00 m x 22.00 m. and 40.00 m x 30.00 m x 8.00 m., respectively.

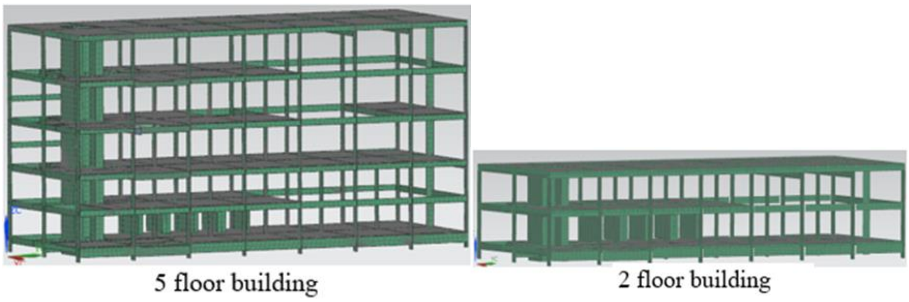


Fig. 2.1. Models of the pressure-resistant buildings.

The buildings were designed to resist the external pressure load of 300 bars, as shown in Fig. 2.2.

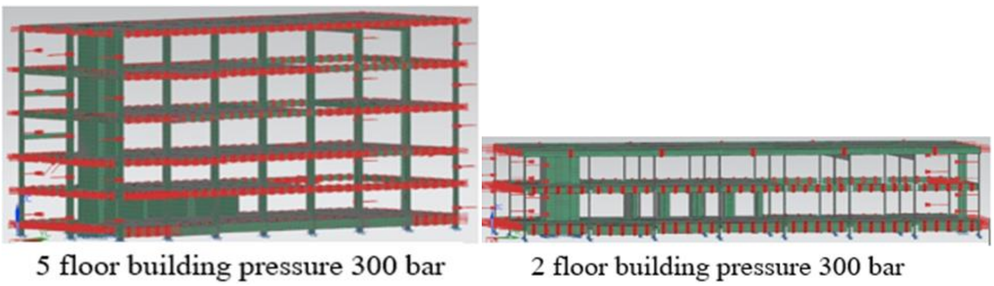


Fig. 2.2. Pressure load of 300 bars affecting the buildings externally.

The pressure load of 300 bars affecting the buildings externally, as shown in Fig. 2.3, caused the maximum reaction force and moment to the columns, as shown in Table 2.1.

DOI:10.4186/ej.2019.23.3.95

Table 2.1. Maximum reaction force and moment caused to the columns on the 5-floor and 2-floor buildings.

Column pressure load of 300 bars		
	5-floor	**2-floor**
Reaction force (kgs)	18533129	15632659
Reaction moment (kgs-m)	3110703	1978084

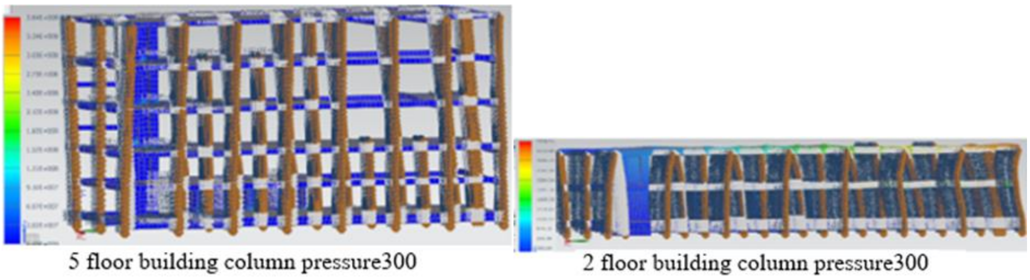


Fig. 2.3. Pressure load of 300 bars on the columns.

The columns' cross-sectional areas and the reinforced steel bars used in the buildings are shown in Fig. 2.4.

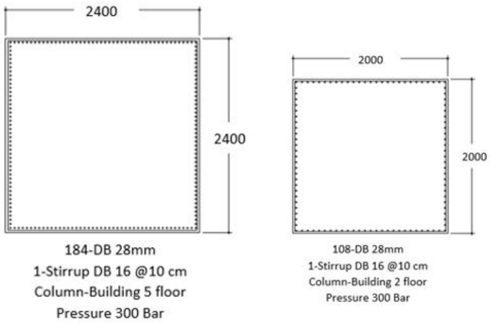


Fig. 2.4. Design of the columns' cross-sectional areas and the reinforced steel bars.

The requirements for designing the pressure-resistant columns on both buildings are shown in Table 2.2.

Table 2.2. Column design requirements for the pressure load of 300 bars on both buildings.

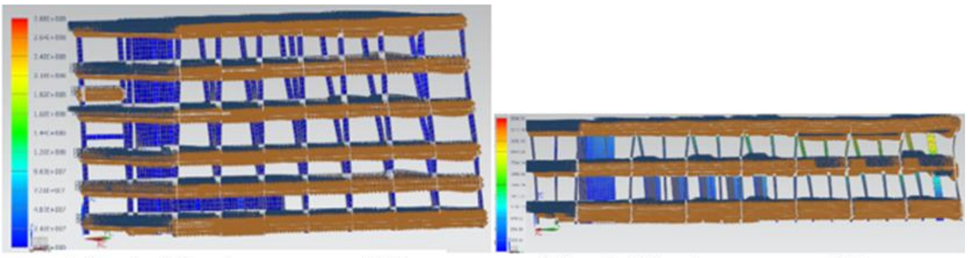
No.	**Column details**	**Property consumption**	
		5-floor building	**2-floor building**
1	Column dimensions (m)	2.40 x 2.40	2.00 x 2.00
2	Column length, H (m)	22.00	8.00
3	Main bars (mm)	184-DB28	108-DB28
4	Stirrup (cm)	1-DB16@10	1-DB16@10
5	Concrete covering (m)	0.05	0.05
6	Yield stress, f_y (ksc)	5000	5000
7	Elastic modulus of steel, E_s (ksc)	2040000	2040000
8	Compressive stress of concrete, f_c' (ksc)	800	1000
9	Elastic modulus of concrete, E_c (ksc)	294353.18	294353.18

The pressure load of 300 bars affecting the buildings externally, as shown in Fig. 2.5, caused the maximum reaction force and moment to the beams, as shown in Table 2.3.

DOI:10.4186/ej.2019.23.3.95

Table 2.3. Maximum reaction force and moment caused to the beams on the 5-floor and 2-floor buildings.

Beam pressure load of 300 bars		
	5-floor	**2-floor**
Reaction force (kgs)	36966608	28484569
Reaction moment (kgs-m)	3111132	2357696



5 floor building beam pressure300 bar   2 floor building beam pressure300 bar

Fig. 2.5. Pressure load of 300 bars on the beams.

The beams' cross-sectional areas and the reinforced steel bars used in the buildings are shown in Fig. 2.6.

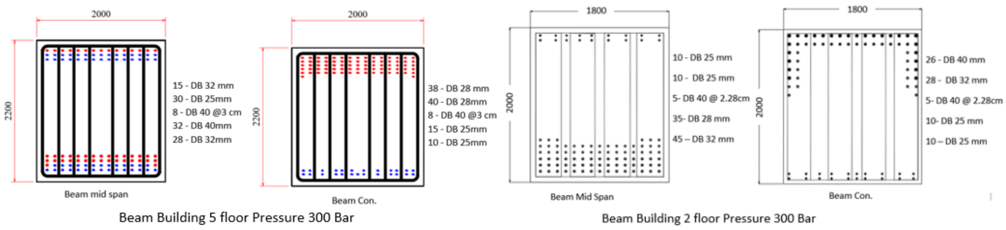


Fig. 2.6. Designs of the beams' cross-sectional areas and the reinforced steel bars.

The requirements for designing the pressure-resistant beams on both buildings are shown in Table 2.4.

Table 2.4. Beam design requirements for the pressure load of 300 bars on both buildings.

No.	**Beam details**	**Property consumption**	
		5-floor building	**2-floor building**
1	Beam dimensions (m)	2.00 x 2.20	1.80 x 2.00
2	Beam length, H (m)	8.00	8.00
3	Main bars (mm)	Mid span : 15-DB32, 30-DB25, 32-DB40, 28-DB32 Beam con : 38-DB28, 40-DB28, 15-DB25, 10-DB25	Mid span : 10-DB25, 10-DB25, 35-DB28, 45-DB32 Beam con : 26-DB40, 28-DB32, 10-DB25, 10-DB25
4	Stirrup (cm)	8-DB40@3	5-DB40@2.28
5	Concrete covering (m)	0.025	0.025
6	Yield stress, f_y (ksc)	5000	5000
7	Elastic modulus of steel, E_s (ksc)	2040000	2040000
8	Compressive stress of concrete, f_c' (ksc)	320	320
9	Elastic modulus of concrete, E_c (ksc)	270117	270117

The pressure load of 300 bars affecting the buildings externally, as shown in Fig. 2.7, caused the maximum reaction force and moment to the slabs, as shown in Table 2.5.

Table 2.5. Maximum reaction force and moment caused to the slabs on the 5-floor and 2-floor buildings.

Slab pressure load of 300 bars		
	5-floor	**2-floor**
Reaction force (kgs)	376361	121338
Reaction moment (kgs-m)	1574108	753934

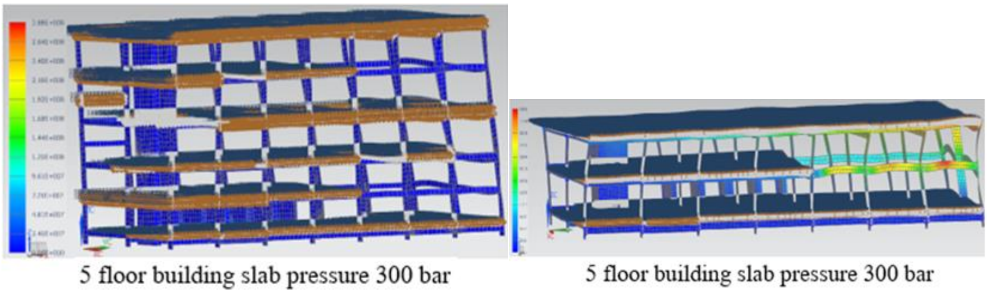


Fig. 2.7. Pressure load of 300 bars on the slabs.

The slabs' cross-sectional areas and the reinforced steel bars used in the buildings are shown in Fig. 2.8.

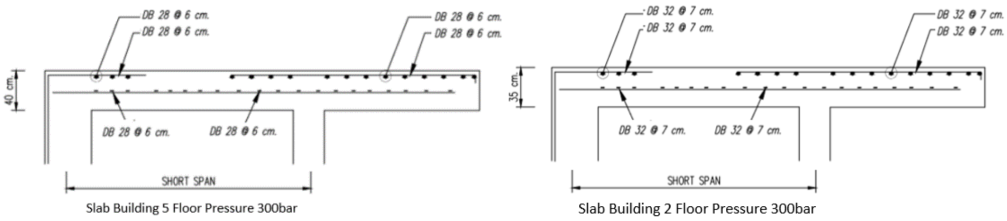


Fig. 2.8. Designs of the slabs' cross-sectional areas and the reinforced steel bars.

The requirements for designing the pressure-resistant slabs on both buildings are shown in Table 2.6.

Table 2.6. Slab design requirements for the pressure load of 300 bars on both buildings.

No.	**Slab details**	**Property consumption**	
		5-floor building	**2-floor building**
1	Slab dimensions (m)	8.00 x 6.00	8.00 x 6.00
2	Slab thickness (cm)	40.00	35.00
3	Main bars (cm)	DB28@6	DB28@6
4	Concrete covering (cm)	2.50	2.50
5	Yield stress, f_y (ksc)	5000	5000
6	Elastic modulus of steel, E_s (ksc)	2040000	2040000
7	Compressive stress of concrete, f_c' (ksc)	280	280
8	Elastic modulus of concrete, E_c (ksc)	252671.32	252671.32

DOI:10.4186/ej.2019.23.3.95

3. Comparative Design for 5-floor and 2-floor Buildings Which Can Resist the External Temperature Load of 300 °C

Figure 3.1 shows the models of 2 temperature-resistant buildings. The heights of these buildings are 5 floors and 2 floors with dimensions of 40.00 m x 30.00 m x 22.00 m. and 40.00 m x 30.00 m x 8.00 m., respectively.

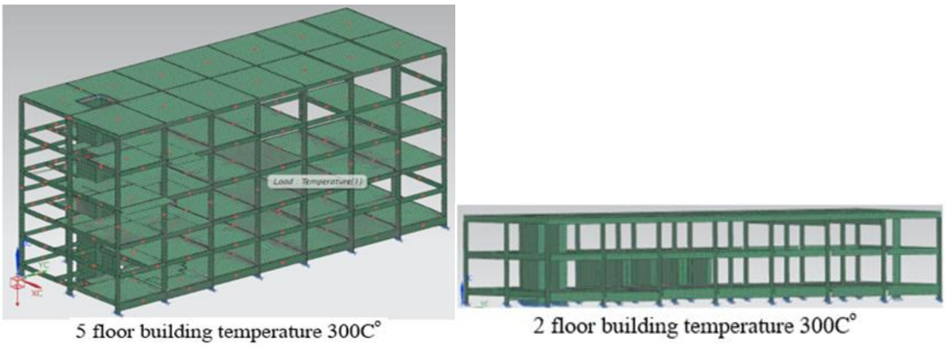


Fig. 3.1. Models of the temperature-resistant buildings.

The buildings were used to test the external temperature load of 300 °C, as shown in Fig. 3.2.

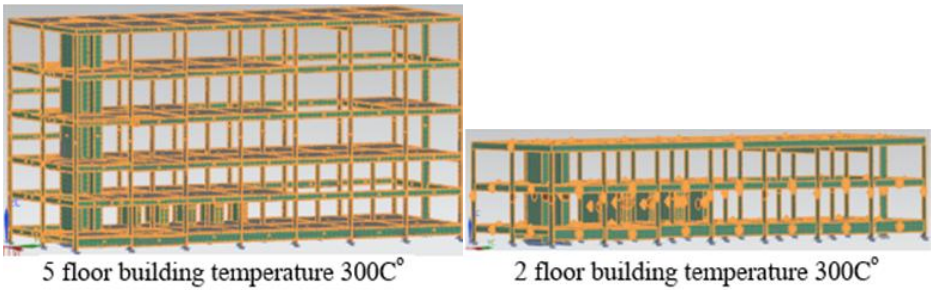


Fig. 3.2. Temperature load of 300 °C affecting the buildings externally.

The temperature load of 300 °C affecting the buildings externally, as shown in Fig. 3.3, caused the maximum reaction force and moment to the columns, as shown in Table 3.1.

Table 3.1. Maximum reaction force and moment caused to the columns on the 5-floor and 2-floor buildings.

Column temperature load of 300 °C		
	5-floor	**2-floor**
Reaction force (kgs)	25448	21183
Reaction moment (kgs-m)	1488	1061

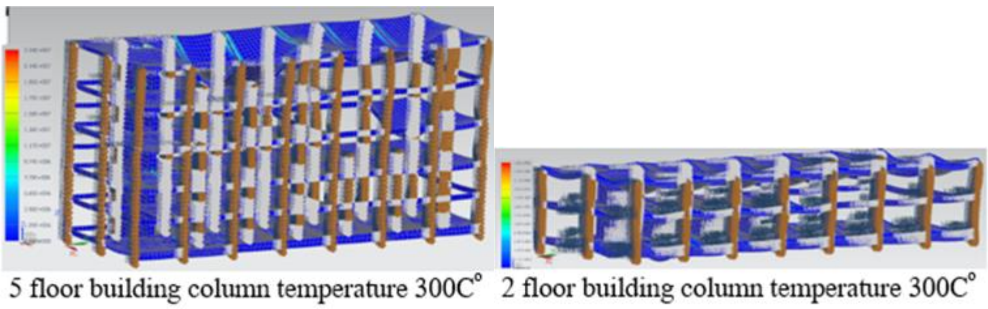


Fig. 3.3. Temperature load of 300 °C on the columns.

The columns' cross-sectional areas and the reinforced steel bars used in the buildings are shown in Fig. 3.4.

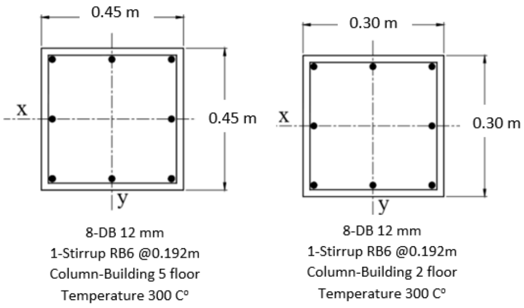


Fig. 3.4. Design of the columns' cross-sectional areas and the reinforced steel bars.

The requirements for designing the temperature-resistant columns on both buildings are shown in Table 3.2.

Table 3.2. Column design requirements for the temperature load of 300 °C on both buildings.

No.	Column details	Property consumption	
		5-floor building	2-floor building
1	Column dimensions (m)	0.45 x 0.45	0.30 x 0.30
2	Column length, H (m)	22.00	8.00
3	Main bars (mm)	8-DB12	8-DB12
4	Stirrup (m)	1-RB6@0.192	1-RB6@0.192
5	Concrete covering (m)	0.05	0.05
6	Yield stress, f_y (ksc)	3000	3000
7	Elastic modulus of steel, E_s (ksc)	2040000	2040000
8	Compressive stress of concrete, f_c' (ksc)	280	240
9	Elastic modulus of concrete, E_c (ksc)	252671.32	233928.19

The temperature load of 300 °C affecting the buildings externally, as shown in Fig. 3.5, caused the maximum reaction force and moment to the beams, as shown in Table 3.3.

Table 3.3. Maximum reaction force and moment caused to the beams on the 5-floor and 2-floor buildings.

Beam temperature load of 300 °C		
	5-floor	2-floor
Reaction force (kgs)	36435	26284
Reaction moment (kgs-m)	1842	743

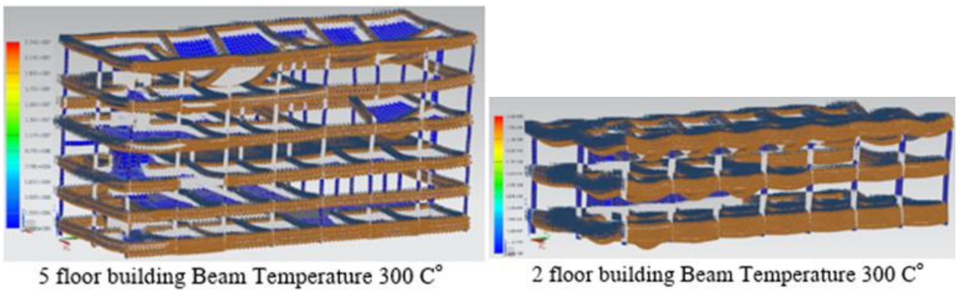


Fig. 3.5. Temperature load of 300 °C on the beams.

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The beams' cross-sectional areas and the reinforced steel bars used in the buildings are shown in Fig. 3.6.

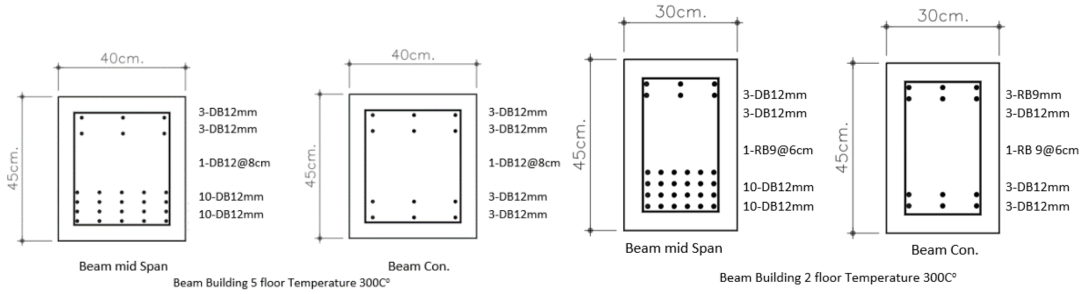


Fig. 3.6. Designs of the beams' cross-sectional areas and the reinforced steel bars.

The requirements for designing the temperature-resistant beams on both buildings are shown in Table 3.4.

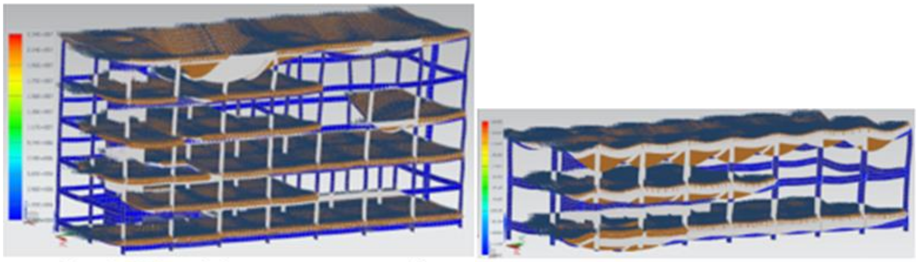
Table 3.4. Beam design requirements for the temperature load of 300 °C on both buildings.

No.	**Beam details**	**Property consumption**	
		5-floor building	**2-floor building**
1	Beam dimensions (m)	0.40 x 0.45	0.30 x 0.45
2	Beam length, H (m)	8.00	8.00
3	Main bars (mm)	Mid span : 3-DB12, 3-DB12, 10-DB12, 10-DB12 Beam con : 3-DB12, 3-DB12, 3-DB12, 3-DB12	Mid span : 3-DB12, 3-DB12, 10-DB12, 10-DB12 Beam con : 3-DB89, 3-DB12, 3-DB12, 3-DB12
4	Stirrup (cm)	1-DB12@8	1-DB89@6
5	Concrete covering (m)	0.025	0.025
6	Yield stress, f_y (ksc)	3000	3000
7	Elastic modulus of steel, E_s (ksc)	2040000	2040000
8	Compressive stress of concrete, f_c' (ksc)	320	280
9	Elastic modulus of concrete, E_c (ksc)	270117.00	252671.32

The temperature load of 300 °C affecting the buildings externally, as shown in Fig. 3.7, caused the maximum reaction force and moment to the slabs, as shown in Table 3.5.

Table 3.5. Maximum reaction force and moment caused to the slabs on the 5-floor and 2-floor buildings.

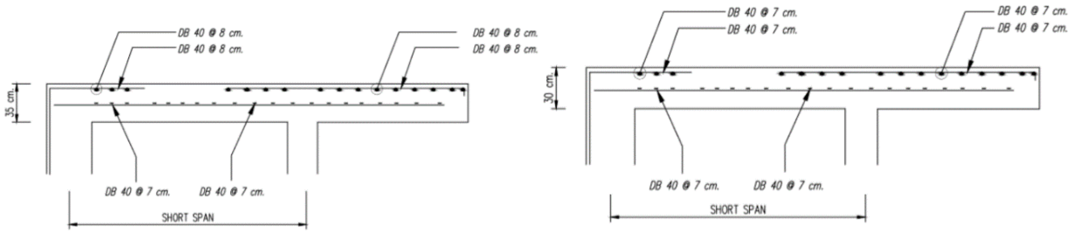
Slab pressure load of 300 °C		
	5-floor	**2-floor**
Reaction force (kgs)	36435.27	7602.45
Reaction moment (kgs-m)	1888.28	2103.00



5 floor building Slab Temperature 300 C°   2 floor building Slab Temperature 300 C°

Fig. 3.7. Temperature load of 300 °C on the slabs.

The slabs' cross-sectional areas and the reinforced steel bars used in the buildings are shown in Fig. 3.8.



Slab Building 5 Floor Temperature 300C°   Slab Building 2 Floor Temperature 300C°

Fig. 3.8. Designs of the slabs' cross-sectional areas and the reinforced steel bars.

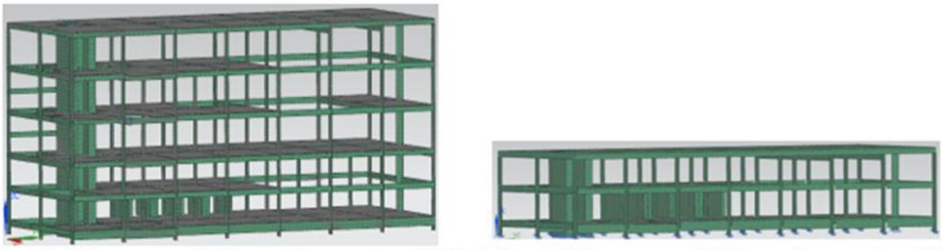
The requirements for designing the temperature-resistant slabs on both buildings are shown in Table 3.6.

Table 3.6. Slab design requirements for the temperature load of 300 °C on both buildings.

No.	**Slab details**	**Property consumption**	
		5-floor building	**2-floor building**
1	Slab dimensions (m)	8.00 x 6.00	8.00 x 6.00
2	Slab thickness (cm)	35.00	30.00
3	Main bars (cm)	DB40@8	DB28@7
4	Concrete covering (cm)	2.50	2.50
5	Yield stress, f_y (ksc)	3000	3000
6	Elastic modulus of steel, E_s (ksc)	2040000	2040000
7	Compressive stress of concrete, f_c' (ksc)	280	280
8	Elastic modulus of concrete, E_c (ksc)	252671.32	252671.32

4. Comparative Design for 5-floor and 2-floor Buildings Which Can Resist the External Pressure Load of 300 Bars and the External Temperature Load of 300 °C

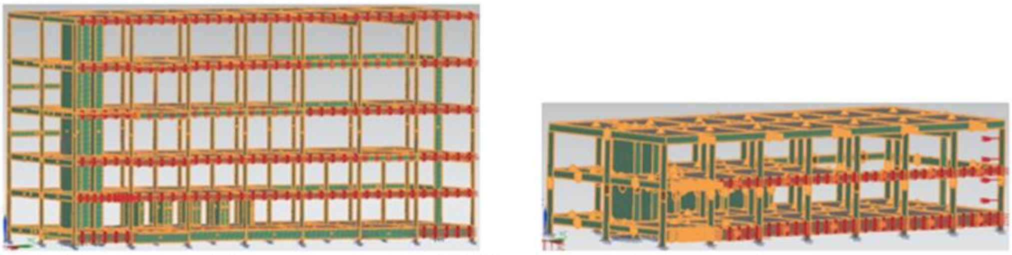
Figure 4.1 shows the models of 2 pressure- and temperature-resistant buildings. The heights of these buildings are 5 floors and 2 floors with dimensions of 40.00 m x 30.00 m x 22.00 m. and 40.00 m x 30.00 m x 8.00 m., respectively.



5 floor building pressure 300 bar and temperature 300C° 2 floor building pressure 300 bar and temperature 300C°

Fig. 4.1. Models of the pressure- and temperature-resistant buildings.

The buildings were used to test the external pressure load of 300 bars and the temperature load of 300 °C, as shown in Fig. 4.2.



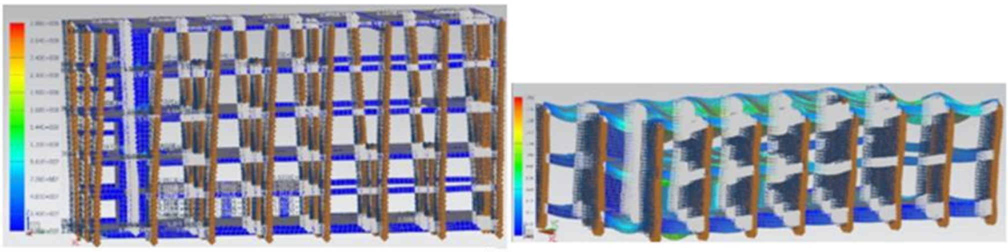
5 floor building pressure 300 bar and temperature 300C° 2 floor building pressure 300 bar and temperature 300C°

Fig. 4.2. Pressure load of 300 bars and temperature load of 300 °C affecting the buildings externally.

The pressure load of 300 bars and the temperature load of 300 °C affecting the buildings externally, as shown in Fig. 4.3, caused the maximum reaction force and moment to the columns, as shown in Table 4.1.

Table 4.1. Maximum reaction force and moment caused to the columns on the 5-floor and 2-floor buildings.

Combined column pressure load of 300 bars and temperature load of 300 °C		
	5-floor	**2-floor**
Reaction force (kgs)	18558577	15653842
Reaction moment (kgs-m)	3112192	1979144



5 floor building column pressure 300 bar and temperature 300C° 2 floor building column pressure 300 bar and temperature 300C°

Fig. 4.3. Combined pressure load of 300 bars and temperature load of 300 °C on the columns.

The columns' cross-sectional areas and the reinforced steel bars used in the buildings are shown in Fig. 4.4.

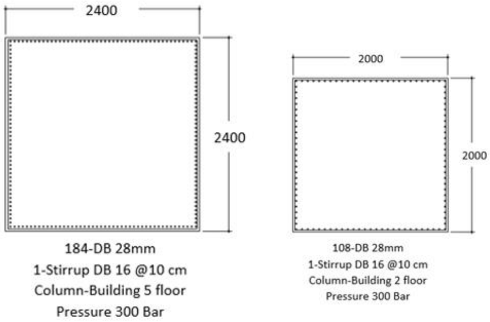


Fig. 4.4. Design of the columns' cross-sectional areas and the reinforced steel bars.

The requirements for designing the pressure- and temperature-resistant columns on both buildings are shown in Table 4.2.

Table 4.2. Column design requirements for the pressure load of 300 bars and temperature load of 300 °C on both buildings.

No.	Column details	Property consumption	
		5-floor building	2-floor building
1	Column dimensions (m)	2.40 x 2.40	2.00 x 2.00
2	Column length, H (m)	22.00	8.00
3	Main bars (mm)	184-DB28	108-DB28
4	Stirrup (cm)	1-DB16@10	1-DB16@10
5	Concrete covering (m)	0.05	0.05
6	Yield stress, f_y (ksc)	5000	5000
7	Elastic modulus of steel, E_s (ksc)	2040000	2040000
8	Compressive stress of concrete, f_c' (ksc)	800	1000
9	Elastic modulus of concrete, E_c (ksc)	294353.18	270117.01

The pressure load of 300 bars and the temperature load of 300 °C affecting the buildings externally, as shown in Fig. 4.5, caused the maximum reaction force and moment to the beams, as shown in Table 4.3.

Table 4.3. Maximum reaction force and moment caused to the beams on the 5-floor and 2-floor buildings.

Combined beam pressure load of 300 bars and temperature load of 300 °C		
	5-floor	2-floor
Reaction force (kgs)	37003043	28510853
Reaction moment (kgs-m)	3112974	2358439

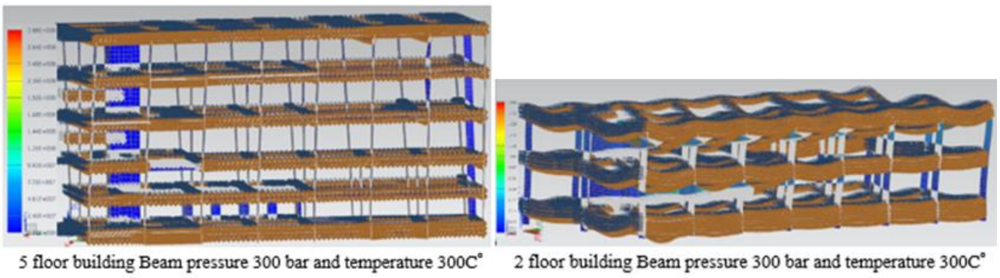


Fig. 4.5. Combined pressure load of 300 bars and temperature load of 300 °C on the beams.

The beams' cross-sectional areas and the reinforced steel bars used in the buildings are shown in Fig. 4.6.

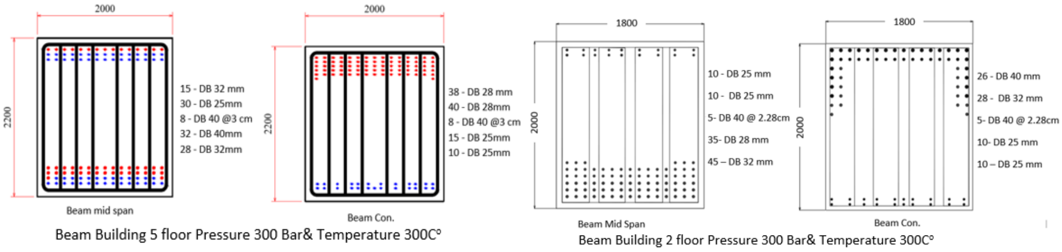


Fig. 4.6. Designs of the beams' cross-sectional areas and the reinforced steel bar.

The requirements for designing the pressure- and temperature-resistant beams on both buildings are shown in Table 4.4.

Table 4.4. Beam design requirements for the pressure load of 300 bars and temperature load of 300 °C on both buildings.

No.	Beam details	Property consumption	
		5-floor building	**2-floor building**
1	Beam dimensions (m)	2.00 x 2.25	1.80 x 2.05
2	Beam length, H (m)	8.00	8.00
3	Main bars (mm)	Mid span : 15-DB32, 30-DB25, 32-DB40, 28-DB32 Beam con : 38-DB28, 40-DB28, 15-DB25, 10-DB25	Mid span : 10-DB25, 10-DB25, 35-DB28, 45-DB32 Beam con : 26-DB40, 28-DB32, 10-DB25, 10-DB25
4	Stirrup (cm)	8-DB40@3.00	5-DB40@2.28
5	Concrete covering (m)	0.025	0.025
6	Yield stress, f_y (ksc)	5000	5000
7	Elastic modulus of steel, E_s (ksc)	2040000	2040000
8	Compressive stress of concrete, f_c' (ksc)	320	320
9	Elastic modulus of concrete, E_c (ksc)	270117.00	270117.00

The pressure load of 300 bars and the temperature load of 300 °C affecting the buildings externally, as shown in Fig. 4.7, caused the maximum reaction force and moment to the slabs, as shown in Table 4.5.

Table 4.5. Maximum reaction force and moment caused to the slabs on the 5-floor and 2-floor buildings.

Combined slab pressure load of 300 bars and temperature load of 300 °C		
	5-floor	**2-floor**
Reaction force (kgs)	412796	128940
Reaction moment (kgs-m)	1575996	756037

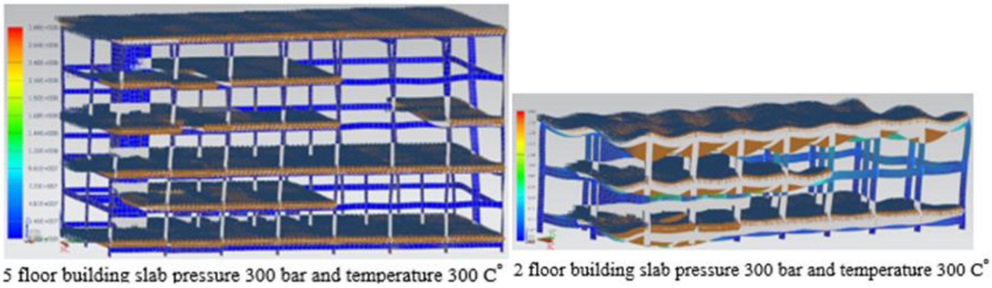


Fig. 4.7. Combined pressure load of 300 bars and temperature load of 300 °C on the slabs.

The slabs' cross-sectional areas and the reinforced steel bars used in the buildings are shown in Fig. 4.8.

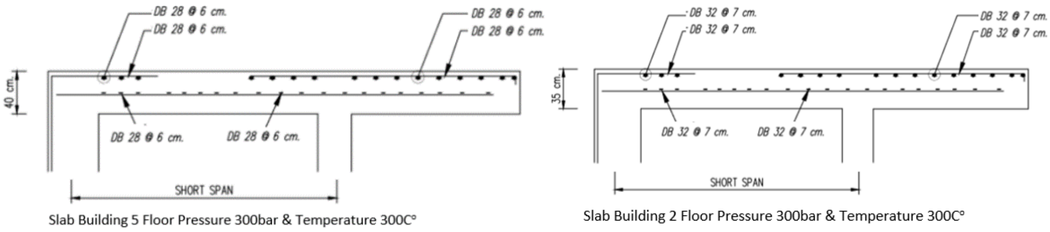


Fig. 4.8. Designs of the slabs' cross-sectional areas and the reinforced steel bars.

The requirements for designing the pressure- and temperature-resistant slabs on both buildings are shown in Table 4.6.

Table 4.6. Slab design requirements for the pressure load of 300 bars and temperature load of 300 °C on both buildings.

No.	Slab details	Property consumption	
		5-floor building	**2-floor building**
1	Slab dimensions (m)	8.00 x 6.00	8.00 x 6.00
2	Slab thickness (cm)	40.00	35.00
3	Main bars (cm)	DB28@6	DB28@6
4	Concrete covering (cm)	2.50	2.50
5	Yield stress, f_y (ksc)	5000	5000
6	Elastic modulus of steel, E_s (ksc)	2040000	2040000
7	Compressive stress of concrete, f_c' (ksc)	320	320
8	Elastic modulus of concrete, E_c (ksc)	270117	270117

5. Summary

The columns' cross-sectional areas and reinforced steel bars used for three structural design tests: the high-pressure (HP) test (300 bars), the high-temperature (HT) test (300 °C), and the high-pressure/high-temperature (HP/HT) test (300 bars and 300 °C), on the 5-floor and 2-floor buildings are shown in Fig. 5.1

DOI:10.4186/ej.2019.23.3.95

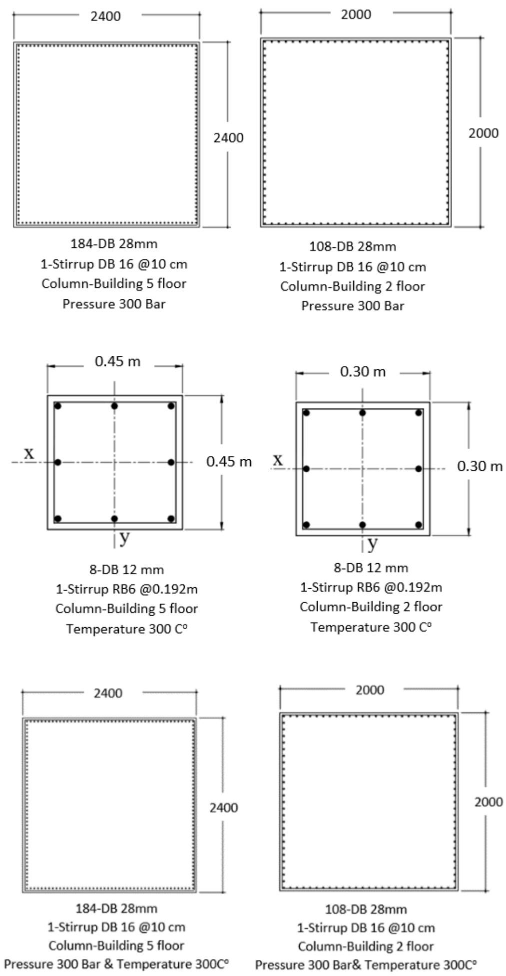


Fig. 5.1. Designs of the columns' cross-sectional areas and the reinforced steel bars on both buildings.

The columns' cross-sectional areas and reinforced steel bars for the 5-floor and 2-floor buildings are different due to variation in the reaction force and moment used to design structural components, as shown in Table 5.1.

Table 5.1. Comparison of the columns' reaction force, reaction moment, and cross-sectional areas on both buildings.

Column	Reaction force (kgs)	Reaction moment (kgs)	Cross-sectional dimensions (m)
HP test (5-floor building)	18533129	3110703	2.40 x 2.40
HP test (2-floor building)	15632659	1978084	2.00 x 2.00
HT test (5-floor building)	25448	1488.28	0.45 x 0.45
HT test (2-floor building)	21183	1060.65	0.35 x 0.30
HP/HT test (5-floor building)	18558577	3112192	2.40 x 2.40
HP/HT test (2-floor building)	15653842	1979144	2.00 x 2.00

From Table 5.1, the reaction force and moment on the 5-floor building are greater than those on the 2-floor building. Also, the reaction force and moment from the pressure loads are greater than those from the temperature loads, resulting in larger columns' cross-sectional areas and the reinforced steel bars.

The beams' cross-sectional areas and reinforced steel bars used for three structural design tests: the high-pressure (HP) test (300 bars), the high-temperature (HT) test (300 °C), and the high-pressure/high-temperature (HP/HT) test (300 bars and 300 °C), on the 5-floor and 2-floor buildings are shown in Fig. 5.2

DOI:10.4186/ej.2019.23.3.95

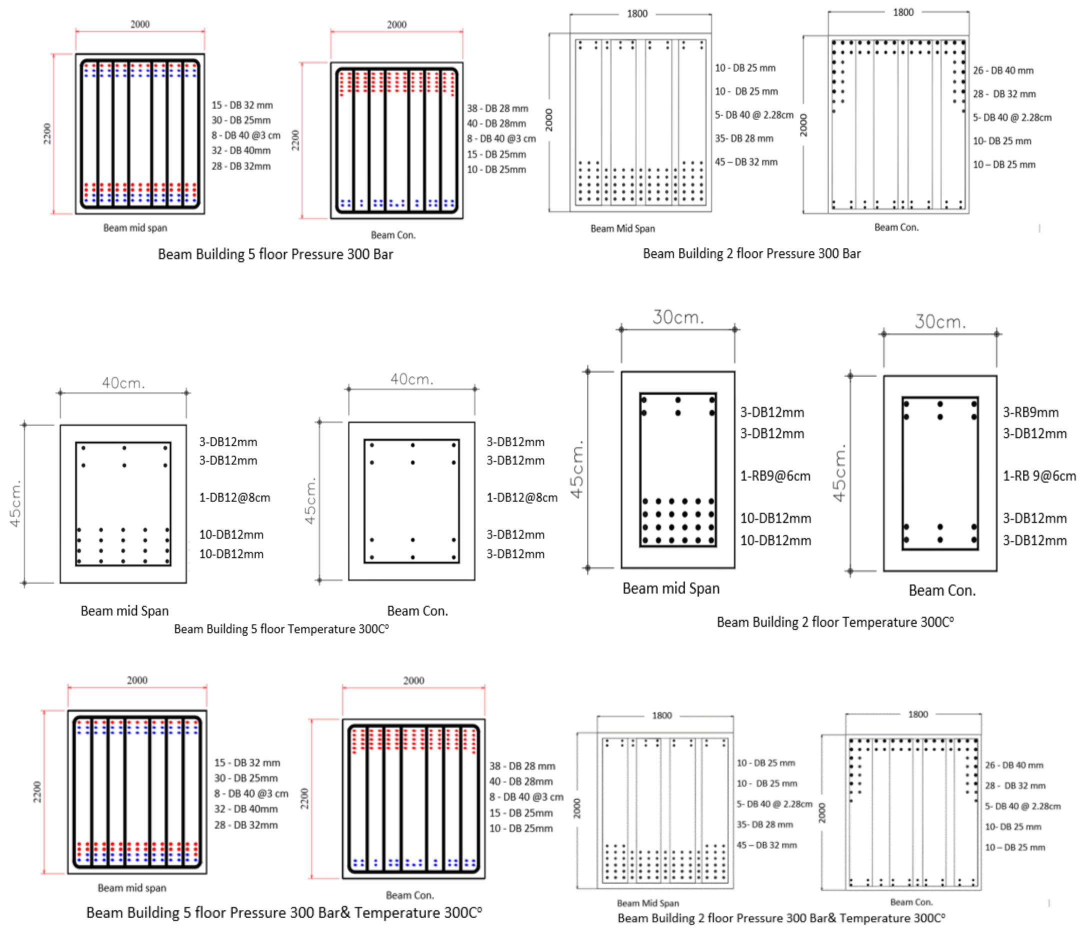


Fig. 5.2. Designs of the beams' cross-sectional areas and the reinforced steel bars on both buildings.

The beams' cross-sectional areas and reinforced steel bars for the 5-floor and 2-floor buildings are different due to variation in the reaction force and moment used to design structural components, as shown in Table 5.2.

Table 5.2. Comparison of the beams' reaction force, reaction moment, and cross-sectional areas on both buildings.

Beam	**Reaction force (kgs)**	**Reaction moment (kgs)**	**Cross-sectional dimensions (m)**
HP test (5-floor building)	36966603	3111132	2.00 x 2.20
HP test (2-floor building)	28484569	237696	1.80 x 2.00
HT test (5-floor building)	36435	1842	0.40 x 0.45
HT test (2-floor building)	26284	742	0.35 x 0.45
HP/HT test (5-floor building)	37003043	3112974	2.00 x 2.20
HP/HT test (2-floor building)	28510853	2358439	1.80 x 2.00

From Table 5.2, the reaction force and moment on the 5-floor building are greater than those on the 2-floor building. Also, the reaction force and moment from the pressure loads are greater than those from the temperature loads, resulting in larger beams' cross-sectional areas and the reinforced steel bars.

The slabs' cross-sectional areas and reinforced steel bars used for three structural design tests: the high-pressure (HP) test (300 bars), the high-temperature (HT) test (300 °C), and the high-pressure/high-temperature (HP/HT) test (300 bars and 300 °C), on the 5-floor and 2-floor buildings are shown in Fig. 5.3

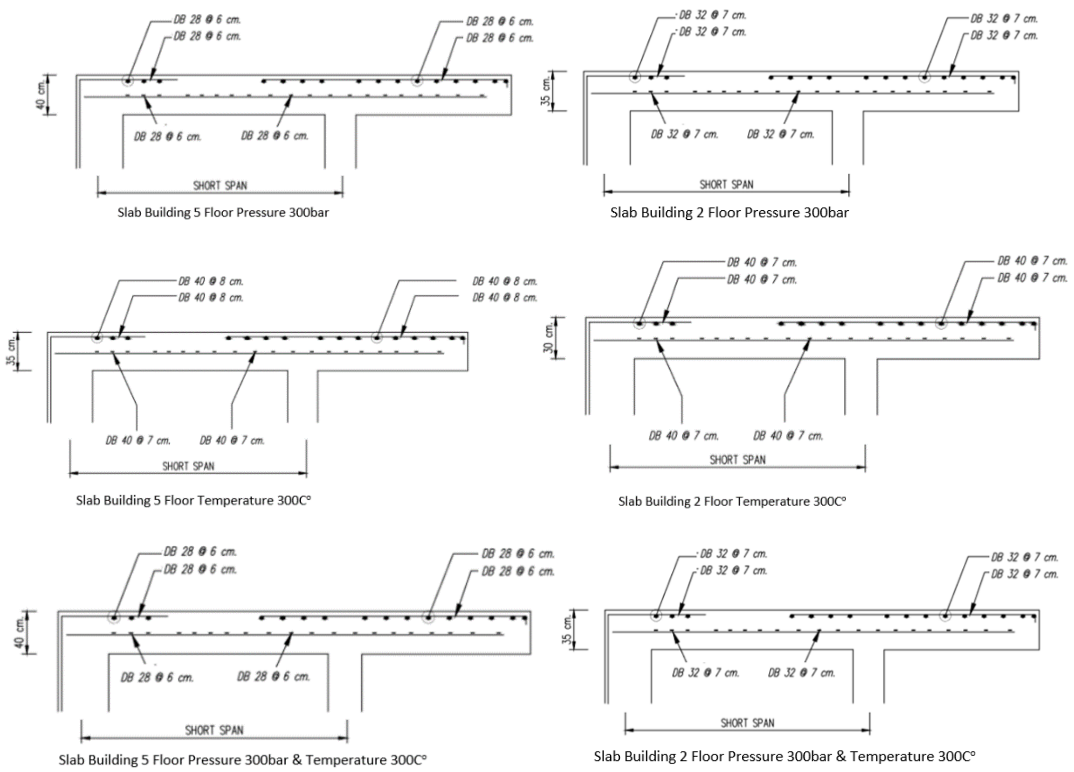


Fig. 5.3. Designs of the slabs' cross-sectional areas and the reinforced steel bars on both buildings.

The slabs' cross-sectional areas and reinforced steel bars for the 5-floor and 2-floor buildings are different due to variation in the reaction force and moment used to design structural components, as shown in Table 5.3.

Table 5.3. Comparison of the slabs' reaction force, reaction moment, and cross-sectional areas on both buildings.

Slab	Reaction force (kgs)	Reaction moment (kgs)	Cross-sectional dimensions (m)
HP test (5-floor building)	376361	1574108	8.00 x 6.00 x 0.40
HP test (2-floor building)	121338	753934	8.00 x 6.00 x 0.35
HT test (5-floor building)	36435	1888.28	8.00 x 6.00 x 0.35
HT test (2-floor building)	7602.45	2103	8.00 x 6.00 x 0.30
HP/HT test (5-floor building)	421796	1575966.33	8.00 x 6.00 x 0.40
HP/HT test (2-floor building)	128940	756037	8.00 x 6.00 x 0.35

From Table 5.3, the reaction force and moment on the 5-floor building are greater than those on the 2-floor building. Also, the reaction force and moment from the pressure loads are greater than those from the temperature loads, resulting in larger slabs' cross-sectional areas and the reinforced steel bars.

6. Conclusions

It can be concluded from the present findings that (1) the pressure loads, temperature loads, and combined pressure and temperature loads on the primary reinforced structures from the external blasts are greater than those from the internal blasts (2) The height of the building affects the loads on the structures. Thus, the loads on the taller structures are greater than the loads on lower structures (3) The pressure load has a greater impact on the primary reinforced structures than the temperature load. These parameters must therefore be taken into consideration in designing pressure- and temperature- resistant buildings.

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