FINITE ELEMENT MODELS OF POST-TENSIONED MASONRY COLUMNS

Ida Ayu Made Budiwati[1]

Abstract: Applications of finite element method in modelling dynamic problems can be used to predict structural dynamic behaviour. In this paper the post-tensioned masonry column was modelled in 2D and 3D using two finite element analysis computer programs, LUSAS and ABAQUS. The frequency analyses were carried out to determine natural frequencies and the corresponding mode shapes of post-tensioned masonry columns. The effects of increasing post-tension force on the natural frequencies of the columns were determined A comparison was made between the 2D and 3D models and also between the two programs used by way of their natural frequency results.

It has been shown that the natural frequencies of post-tensioned masonry column with zero post-tension force comprise the natural frequencies of its individual components (the masonry column with the concrete cap only and the post-tensioning bar only). With increasing post-tension force the natural frequency increased.

Natural frequencies obtained using 2D models were in general higher than those of 3D models and ABAQUS results were almost smaller than LUSAS results. Nevertheless, it is appropriate to model dynamic behaviour of post-tensioned masonry in 2D and to use any of the two programs.

Keywords: LUSAS, ABAQUS, finite element software, natural frequency, post-tensioned masonry.

PEMODELAN MASONRY DENGAN PRATEGANG MENGGUNAKAN SOFTWARE ELEMEN HINGGA

Abstrak: Aplikasi dari metode finite elemen dalam pemodelan masalah dinamis bisa digunakan untuk memprediksi perilaku dinamis dari struktur. Didalam tulisan ini kolom masonry dengan prategang dibuatkan pemodelan 2D dan 3D dengan menggunakan dua buah program komputer berbasis finite element, LUSAS and ABAQUS. Analisis frekuensi dilakukan terhadap masonry kolom dengan prategang untuk menentukan frekuensi natural dengan mode shapenya yang bersesuaian. Pengaruh dari peningkatan gaya prategang terhadap frekuensi natural dari kolom tersebut ditentukan. Perbandingan dibuat antara hasil frekuensi naturalnya dari model 2D dan model 3D dan juga antara hasil yang didapat dari kedua program yang digunakan.

Terlihat bahwa frekuensi natural dari kolom masonry tanpa gaya prategang terdiri dari frekuensi natural dari masing-masing komponen (kolom masonry dengan penutup beton saja dan besi prategang saja). Dengan meningkatkan gaya prategang maka natural fekuensi akan meningkat.

Frekuensi natural dari model 2D pada umumnya lebih kecil dibandingkan dari model 3D dan hasil dari ABAQUS memberikan nilai yang lebih kecil secara umum dibandingkan dengan hasil dari LUSAS. Sekalipun demikian perilaku dinamis dari masonry dengan prategang cukup memadai hanya dimodel dengan 2D dan dengan menggunakan program manapun.

Kata kunci: LUSAS, ABAQUS, software elemen hingga, frekuensi alami, masonry dengan prategang.

[1] Dosen Jurusan Teknik Sipil, Fakultas Teknik, Universitas Udayana, Denpasar.

Introduction

Since the advent of computers, many program packages have been introduced to help designers to solve problems such as the analysis of structures, design of structures, generation of drawings, etc. Software has been built to solve problems from the simple to the complex. For instance, a finite element computer program is used for the analysis of simple and complex structures and produces member sizes, stress distributions, displacements or natural frequencies.

Applications of finite element method in modelling dynamic problems can be used for example to predict structural dynamic behaviour. The method is particularly useful when alternatives such as analytical or experimental methods can not be used. The advantage of using the FE method is to provide a quick, complete and inexpensive solution. The availability of finite element computer packages for structural analysis such as LUSAS, ABAQUS, SAP, ANSYS, etc., can give the advantages for designer to understand the behaviour of structures under different load and design conditions. Ji and Mandal (2004) used LUSAS and ABAQUS for modelling a cantilever grandstand and studied its dynamic behaviour. Chan (2002) used LUSAS to study dynamic behaviour of CHS steel numerically. The use of any availability software is dependent on the type analysis conducted, the capability of the software itself and the convenient of the user.

This paper presents the numerical analyses for determining the natural frequencies of the post-tensioned masonry columns. Natural frequencies of post-tensioned masonry columns with different levels of post-tension forces were determined together with their mode shapes. The columns were modelled in two and three dimensional using two finite element computer programs namely LUSAS and ABAQUS. The results from the 3D model were compared to those of the 2D model. A further comparison was made between the LUSAS and ABAQUS results.

Finite Element Models

LUSAS analyses

A similar procedure was followed for the numerical analyses when using each finite element software package. Firstly, a model was created using appropriate elements with a suitable number of mesh divisions. The geometric properties, material properties and support conditions were then assigned. Finally, loadings (post-tension forces in this case) were applied.

Plan and elevation of the post-tensioned masonry column used for the investigation are shown in Figure 1. It comprises masonry column, concrete cap and post-tensioning bar. The masonry column was made of clay brick and had an overall cross section of 328 x 328 mm with a 123 x 123 mm void inside and a height of 1125 mm. It was topped with a 200 mm thick solid concrete cap which had a 60mm diameter hole at its centre. A 25mm diameter post-tensioning bar was positioned between the base of the masonry column and the concrete cap.

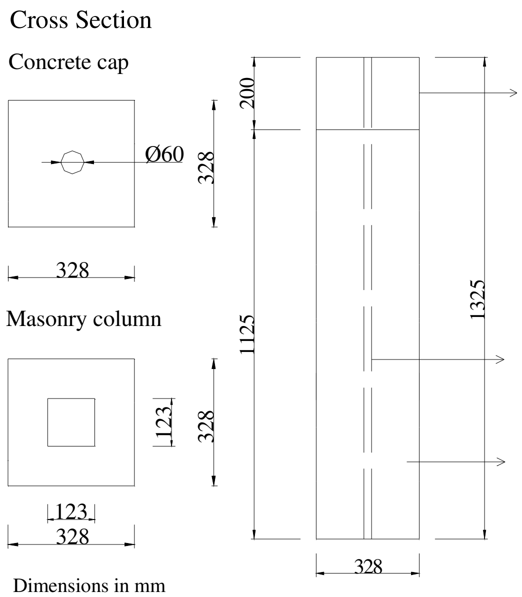


Figure 1. Plan and elevation of post-tensioned masonry column

Modelling of the post-tensioned masonry column

LUSAS - 2D Model

The post-tensioned masonry column was modelled using 2D beam elements. The features of the model contained three connected components which were masonry column, concrete cap and post-tensioning bar. The bottom of masonry column and post-tensioning bar were assummed to have fixed ends.

In the 2D model, the masonry column and the concrete cap were created using thick elements (BEAM elements) which include shear effects in the analysis. Thin beam elements (BM3 elements) were used to model the post-tensioning bar in which shear effects are ignored. These elements were chosen to accommodate the default frequency analysis provided by LUSAS. The overall length of the masonry column and the concrete cap was 1325mm. The post-tensioning bar length was 1325mm. The 2D model is shown in Figure 2. The lines connecting point 1 to point 2 and point 2 to point 3 represent the masonry column and the concrete cap respectively. The line connecting point 1 to point 3 represents the post-tensioning bar. The elements comprising the model were divided into a number of mesh divisions. The appropriate geometric and material properties are given in Table 1. Point 1 was taken to be a fixed support.

Frequency analyses (Eigenvalue analyses) were carried out for the individual components of the post-tensioned masonry column. The natural frequencies for the masonry column with the concrete cap only and the post-tensioning bar only were determined. The masonry column with the concrete cap only was modelled as a cantilever column while the post-tensioning bar only was modelled as a fixed ended beam. No post-tension force was applied to the components.

Frequency analyses were carried out to determine the natural frequencies of the post-tensioned masonry column. The post-tension force was applied to elements of the post-tensioning bar using either a temperature load or an initial stress-strain technique. The applied load caused tension stress in the post-tensioning bar and compression stress in the column. The temperature load was obtained by decreeasing the temperature of the elements below a given initial temperature. For the initial stress-strain technique, the required post-tension force value was applied to the post-tensioning bar elements.

Natural frequencies of the post-tensioned masonry column for a number of differrent post-tension levels were determined. No damping was considered throughout the analyses. Before performing the frequency analyses, a non-linear geometric analysis was carried out in order to take into account the effect of post-tension force on the stiffness of the model. The effects of a number of post-tension forces from 0kN to 276kN on natural frequencies of post-tensioned masonry columns were analysed. These values were taken from the post-tension forces that had been applied to one of the post-tensioned masonry columns in the experiment. The first five natural frequencies of the post-tensioned masonry column were determined together with their mode shapes.

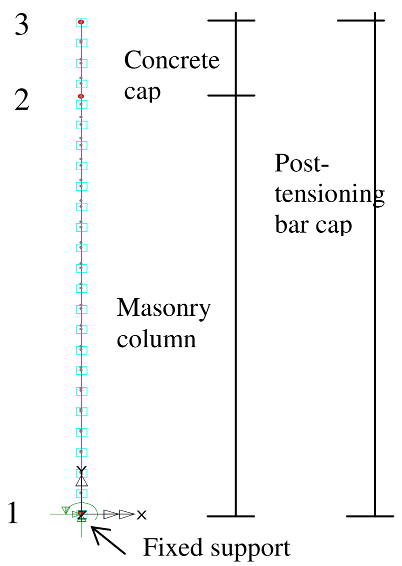


Figure 2. 2D Model – LUSAS

Table 1. Geometric and material properties of post-tensioned clay brick masonry columns

Property	Clay brick masonry column	Concrete cap	Post-tensioning bar
Modulus of elasticity, E (N/m^2)	1.35E+10	3.00E+10	1.70E+11
Poison ratio, ν	0.2	0.2	0.3
Mass density (kg/m^3)	2000	2400	7800
Coefficient of thermal expansion, α ($/^oC$)	1.00E-05	1.00E-05	1.20E-05
Length, L (m)	1.125	0.200	1.325
Second moment of area, I (m^4)	9.45E-04	9.64E-04	1.92E-08
Area, A (m^2)	9.25E-02	1.06E-01	4.91E-04

LUSAS - 3D Model

The post-tensioned masonry column was modelled using 3D solid continuum elements. In the 3D model, the masonry column, the concrete cap and the post-tensioning bar were created using hexahedral-linear elements (HX8M elements). The 3D model is shown in Figure 3. The top end of the post-tensioning bar was fixed to the top end of the concrete cap using a 10 mm steel plate. This steel plate was modelled using the HX8M elements. No attempts were made to model individual clay bricks and mortar joints in order to simplify the post-tensioned masonry model. The material properties used for the model are given in Table 1. Fixed supports were applied to the bottom ends of masonry column and of post-tensioning bar.

Frequency analyses using this 3D model were carried out for the individual components of the post-tensioned masonry column. The natural frequencies for the masonry column with the concrete cap only and the post-tensioning bar only were determined. The masonry column with the concrete cap only was modelled as a cantilever column while the post-tensioning bar only was modelled as a fixed ended beam. No post-tension force was applied to the components.

Frequency analyses were also carried out to determine the natural frequencies of the post-tensioned masonry column. The post-tension force was applied to the post-tensioning bar as a temperature load. Natural frequencies of the post-tensioned masonry column for a number of different post-tension levels were determined. Similar to the 2D model the effect of damping was neglected throughout the analyses. Before performing the frequency analyses, a non-linear geometric analysis was carried out in order to take into account the effect of post-tension force in the stiffness of the modelled structure. The effects of a number of post-tension forces on natural frequencies of post-tensioned masonry columns were analysed. The post-tension force values applied were the same as those for the 2D model. The first five natural frequencies of the post-tensioned masonry column were determined together with their mode shapes.

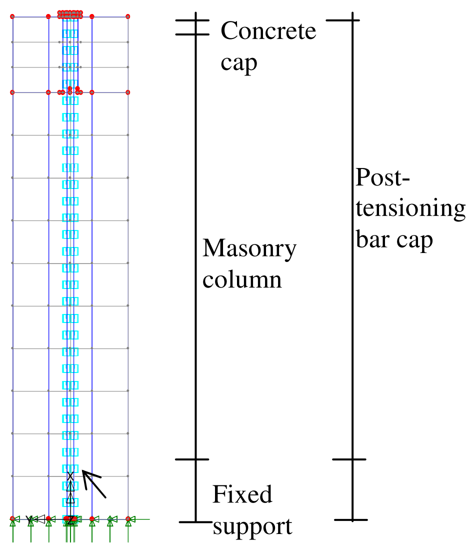


Figure 3. 3D Model – LUSAS

ABAQUS analyses

Additional numerical analyses using ABAQUS were intended to confirm the results that were generated by LUSAS. The procedure used to determine the natural frequencies of the post-tensioned masonry columns in ABAQUS is similar to those used with LUSAS. The findings are summarised below.

Modelling of the post-tensioned masonry column

ABAQUS - 2D Model

The elements used were first order beam elements (Type B21) for the masonry column and the concrete cap. The second order beam elements (Type B22) were used for the post-tensioning bar. All the elements included shear effects in the analysis. Geometric properties, material properties and support conditions applied were the same as those in LUSAS. The post-tension forces were applied using the temperature load facility. Non-linear geometric analysis was performed to include the applied force, which affects the stiffness of the model. Eigenvalue analyses were conducted to obtain the natural frequencies and mode shapes of the post-tensioned masonry column. The post-tension force values applied were the same as those for the LUSAS model. The first five natural frequencies of the post-tensioned masonry column were determined together with their mode shapes.

ABAQUS - 3D Model

In the ABAQUS analyses, 8-node brick elements (Type C3D8I) were used to create the 3D model which comprised the masonry column, the concrete cap and the post-tensioning bar. These elements are similar as those used in the LUSAS 3D model. Natural frequencies of post-tensioned masonry column and its corresponding mode shapes on different post-tension forces were determined. The post-tension force values applied were the same as those for the LUSAS model. The first five natural frequencies of the post-tensioned masonry column were determined together with their mode shapes.

RESULT AND DISCUSSION

LUSAS results

Natural frequencies of the post-tensioned masonry column and its individual components for both LUSAS 2D and 3D models without post-tension forces are presented in Table 2.

Table 2. Natural frequencies of post-tensioned masonry column and its components, LUSAS 2D and 3D Models

LUSAS						
Natural Frequency (Hz)	2D Model			3D Model		
	Masonry column + concrete cap only	Post-tensioning bar only	Post-tensioned masonry column	Masonry column + concrete cap only	Post-tensioning bar only	Post-tensioned masonry column
f_1	73.45	59.16	58.84	73.46	57.84	55.84
f_2	380.16	163.03	73.43	376.79	160.06	73.55
f_3	828.88	319.44	163.23	871.05	315.70	155.55
f_4	1212.35	527.71	319.56	1393.59	526.19	306.59
f_5	1495.36	787.74	379.75	1908.05	794.28	383.76

It was found that the natural frequencies of the post-tensioned masonry column comprise the natural frequencies of its individual components (the masonry column with the concrete cap only and the post-tensioning bar only). The first, third and fourth natural frequencies of the post-tensioned masonry column were nearly the same as the first, second and third natural frequencies of the post-tensioning bar only. The second and fifth natural frequencies were the same as the first and second natural frequencies of the masonry column with the concrete cap only. The same behaviour was shown for both 2D and 3D models.

The first five natural frequencies of the post-tensioned masonry column with different levels of post-tension force determined from the LUSAS 2D model are presented in Table 3. The associated mode shapes are shown in Figure 4.

Table 3. Natural frequencies of post-tensioned masonry column - LUSAS 2D Model

LUSAS 2D Model					
Post-tension force (kN)	Natural frequency (Hz)				
	f_1	f_2	f_3	f_4	f_5
0.00	58.84	73.43	163.32	319.56	379.75
18.25	64.73	73.96	172.20	329.35	379.83
32.79	68.39	74.97	178.95	336.93	379.91
40.60	69.77	75.95	182.46	340.92	379.96
65.96	71.71	81.18	193.39	353.47	380.21
101.39	72.34	89.51	207.62	369.48	381.31
134.94	72.57	96.93	220.18	377.68	388.67
156.55	72.67	101.41	227.88	378.66	397.27
184.83	72.77	106.99	237.54	379.09	409.10
219.96	72.87	113.50	248.97	379.33	423.58
252.20	72.95	119.14	258.98	379.47	436.50
275.99	73.01	123.12	266.10	379.55	445.80

For every mode, the deflected shapes of the post-tensioned masonry column and its individual components were plotted separately. Only the first two mode shapes are presented, for post-tension forces P = 0kN, P = 65.36kN and P = 275.99kN.

The first five natural frequencies of post-tensioned masonry column with different levels of post-tension force from the LUSAS 3D model are presented in Table 4. The associated mode shapes are shown in Figure 5. For every mode, the deflected shapes of the post-tensioned masonry column as well as its individual components were each plotted separately. Only the first two mode shapes are presented, for post-tension forces P = 0kN and P = 275.99kN.

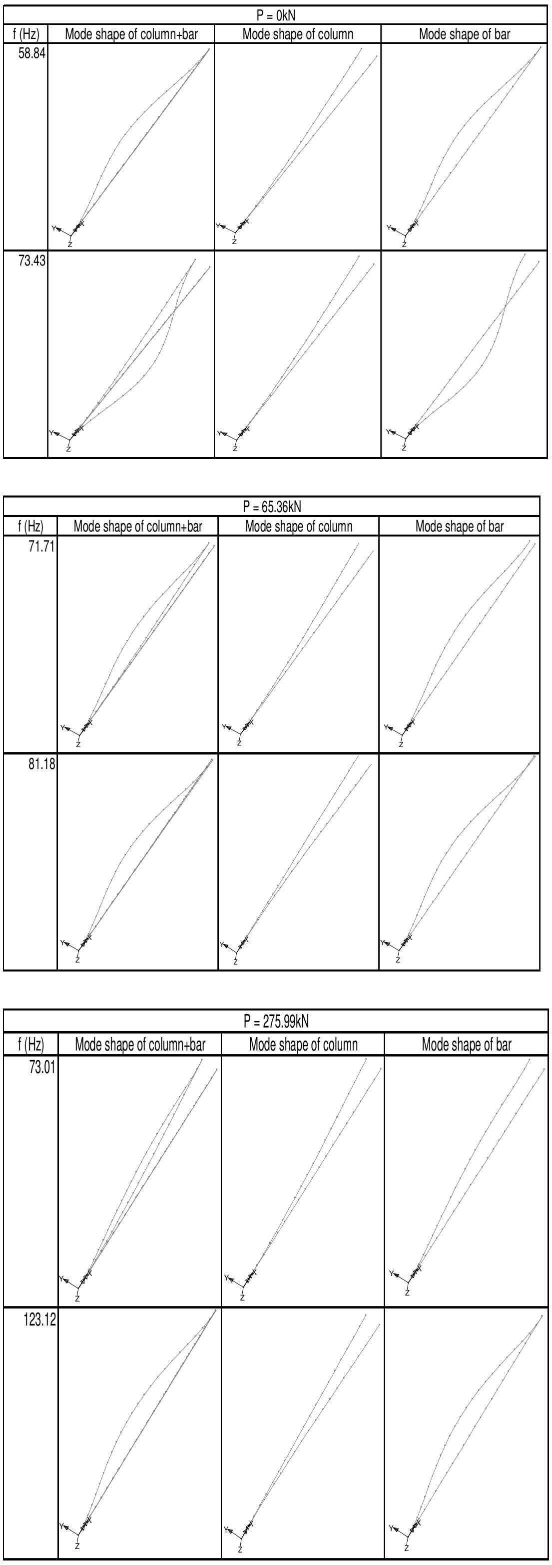
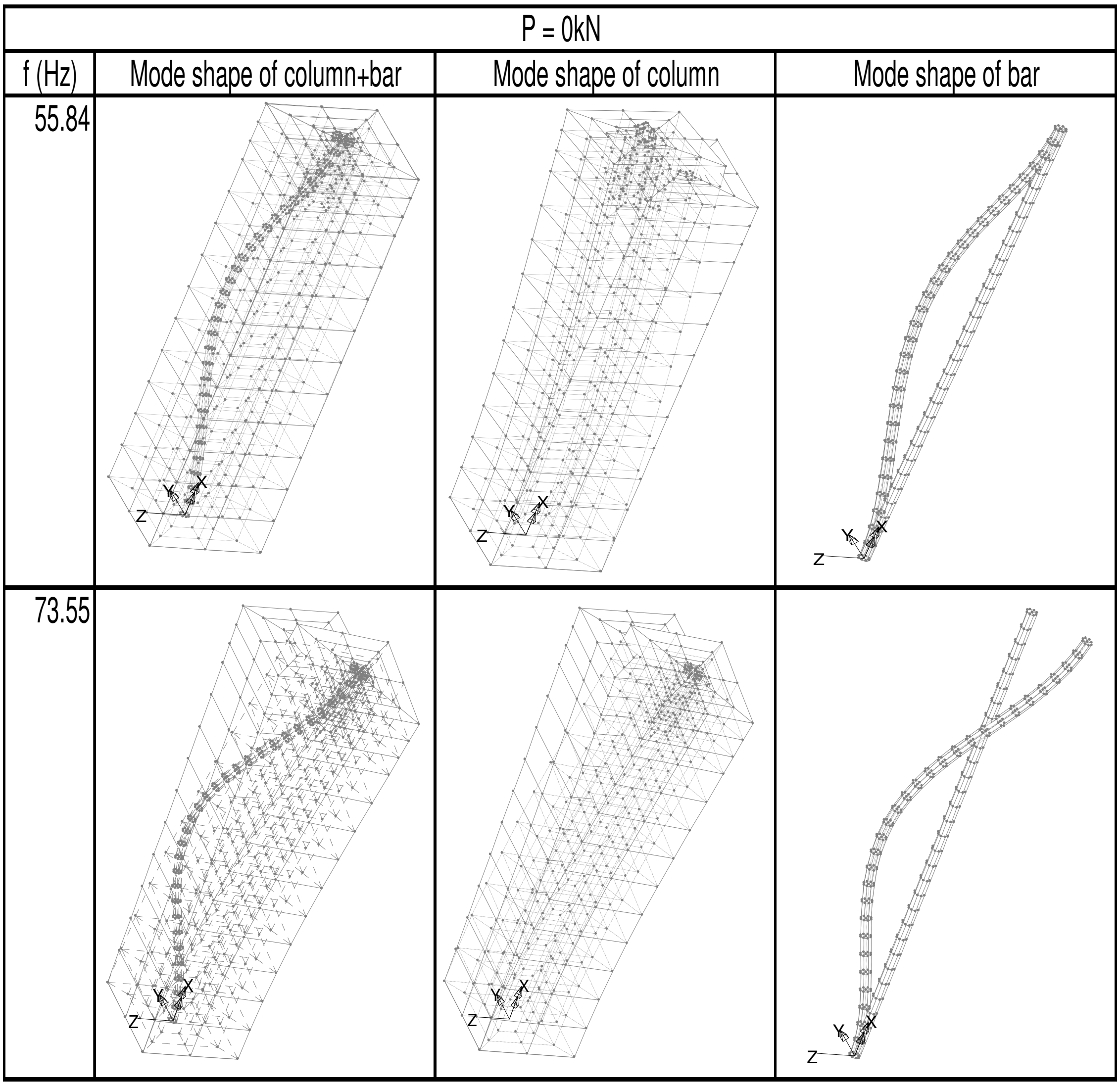


Figure 4. Mode shapes of a post-tensioned masonry column - LUSAS 2D Model

Table 4. Natural frequencies of post-tensioned masonry column - LUSAS 3D Model

LUSAS 3D Model					
Post-tension force (kN)	Natural frequency (Hz)				
	f_1	f_2	f_3	f_4	f_5
0.00	55.84	73.55	155.55	306.59	383.76
18.25	61.75	73.84	164.15	316.06	383.79
32.79	65.77	74.31	170.68	323.40	383.82
40.60	67.60	74.76	174.07	327.26	383.84
65.96	71.13	78.12	184.64	339.47	383.92
101.39	72.23	85.60	198.39	355.66	384.17
134.94	72.49	92.65	210.52	369.79	384.92
156.55	72.58	96.95	217.94	377.23	386.73
184.83	72.64	102.30	227.27	381.48	394.24
219.96	72.70	108.56	238.29	382.50	407.35
252.20	72.72	113.97	247.94	382.77	419.59
275.99	72.74	117.79	254.80	382.87	428.48



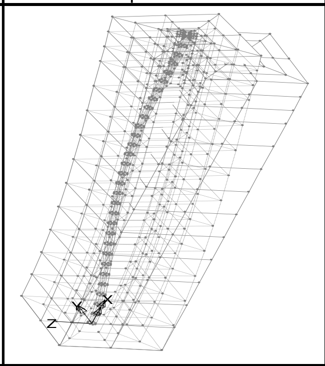
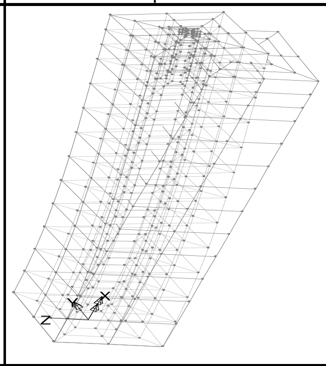
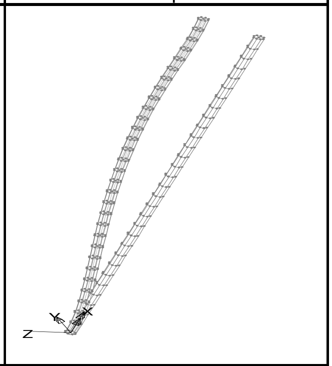
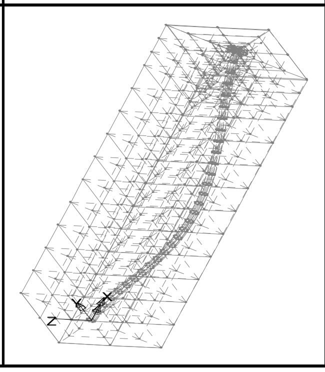
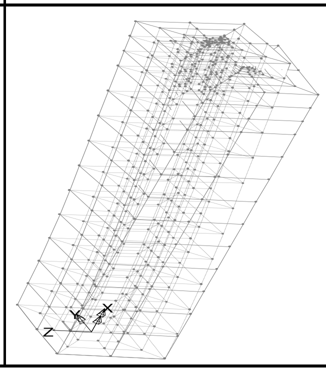
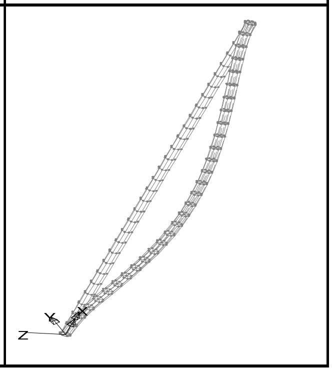
P = 275.99kN			
f (Hz)	Mode shape of column+bar	Mode shape of column	Mode shape of bar
72.74			
117.79			

Figure 5. Mode shapes of a post-tensioned masonry column- LUSAS 3D Model

Natural frequency comparisons between the LUSAS 2D and 3D models are given in Table 5 and Figure 6. Very similar results were obtained from both models. The same behaviour was shown by both models for the natural frequency and post-tension force relations. The LUSAS 2D results were typically larger than the 3D results with differences ranging from -1% to +5%.

Table 5. Natural frequency differences between LUSAS 2D and 3D Models

LUSAS					
Post-tension force (kN)	(2D-3D)/3D (%)				
	f_1	f_2	f_3	f_4	f_5
0.00	5.38	-0.16	5.00	4.23	-1.05
18.25	4.83	0.17	4.90	4.20	-1.03
32.79	3.99	0.88	4.85	4.18	-1.02
40.60	3.21	1.60	4.82	4.17	-1.01
65.96	0.82	3.93	4.74	4.12	-0.97
101.39	0.16	4.56	4.65	3.89	-0.74
134.94	0.11	4.61	4.59	2.13	0.97
156.55	0.13	4.60	4.56	0.38	2.73
184.83	0.18	4.58	4.52	-0.63	3.77
219.96	0.24	4.56	4.48	-0.83	3.98
252.20	0.32	4.53	4.45	-0.86	4.03
275.99	0.37	4.52	4.43	-0.87	4.04

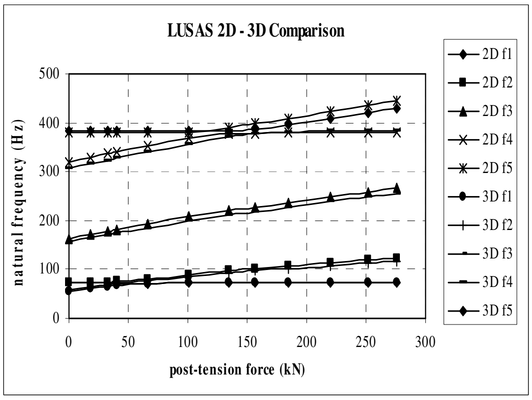


Figure 6. Comparison between natural frequencies LUSAS 2D and 3D Models

Results of mode shape of LUSAS 2D and 3D models were also similar. For zero post-tension force, the first modes were dominated by the post-tensioning bar behaviour and the second modes by the column behaviour. Increasing post-tension force changed behaviour of the post-tensioned masonry column where the first modes were dominated by column behaviour and the second modes by post-tensioning bar behaviour.

ABAQUS results

The first five natural frequencies of the post-tensioned masonry column at different levels of post-tension determined using the ABAQUS 2D model are presented in Table 6. The associated mode shapes are shown in Figure 7 where the first five mode shapes are presented, for typical post-tension forces of P = 18.25kN and P = 65.36kN.

The first five natural frequencies of post-tensioned masonry column at different levels of post-tension determined using the ABAQUS 3D model are presented in Table 7. The associated mode shapes are shown in Figure 8 where the first five mode shapes are presented, for typical post-tension forces P = 18.25kN and P = 65.36kN.

Table 6. Natural frequencies of post-tensioned masonry column - ABAQUS 2D Model

ABAQUS 2D Model					
Post-tension force (kN)	Natural frequency (Hz)				
	f_1	f_2	f_3	f_4	f_5
0.00	58.78	73.88	162.90	318.32	397.19
18.25	64.70	74.35	171.79	328.17	397.22
32.79	68.45	75.25	178.55	335.80	397.26
40.60	69.90	76.15	182.06	339.81	397.28
65.96	71.99	81.19	193.00	352.51	397.37
101.39	72.61	89.46	207.24	369.34	397.63
134.94	72.79	96.86	219.81	383.99	398.45
156.55	72.85	101.35	227.51	391.45	400.61
184.83	72.91	106.92	237.17	395.21	409.09
219.96	72.95	113.43	248.61	396.07	422.91
252.20	72.98	119.06	258.62	396.32	435.68
275.99	72.99	123.03	265.74	396.42	444.94

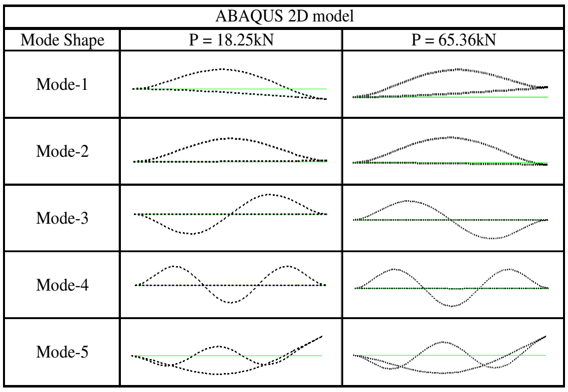


Figure 7. Mode shapes of a post-tensioned masonry column, ABAQUS 2D Model

Table 7. Natural frequencies of post-tensioned masonry column - ABAQUS 3D Model

ABAQUS 3D Model					
Post-tension force (kN)	Natural frequency (Hz)				
	f_1	f_2	f_3	f_4	f_5
0.00	56.21	73.40	156.07	306.01	378.63
18.25	62.09	73.71	164.62	315.38	378.66
32.79	66.07	74.22	171.11	322.63	378.70
40.60	67.85	74.71	174.48	326.44	378.72
65.96	71.13	78.29	184.97	338.50	378.82
101.39	72.13	85.86	198.61	354.43	379.11
134.94	72.38	92.89	210.64	368.11	380.11
156.55	72.46	97.17	217.99	374.41	382.92
184.83	72.53	102.49	227.22	377.02	391.90
219.96	72.58	108.71	238.12	377.67	405.14
252.20	72.61	114.08	247.65	377.88	417.23
275.99	72.63	117.87	254.42	377.96	425.97

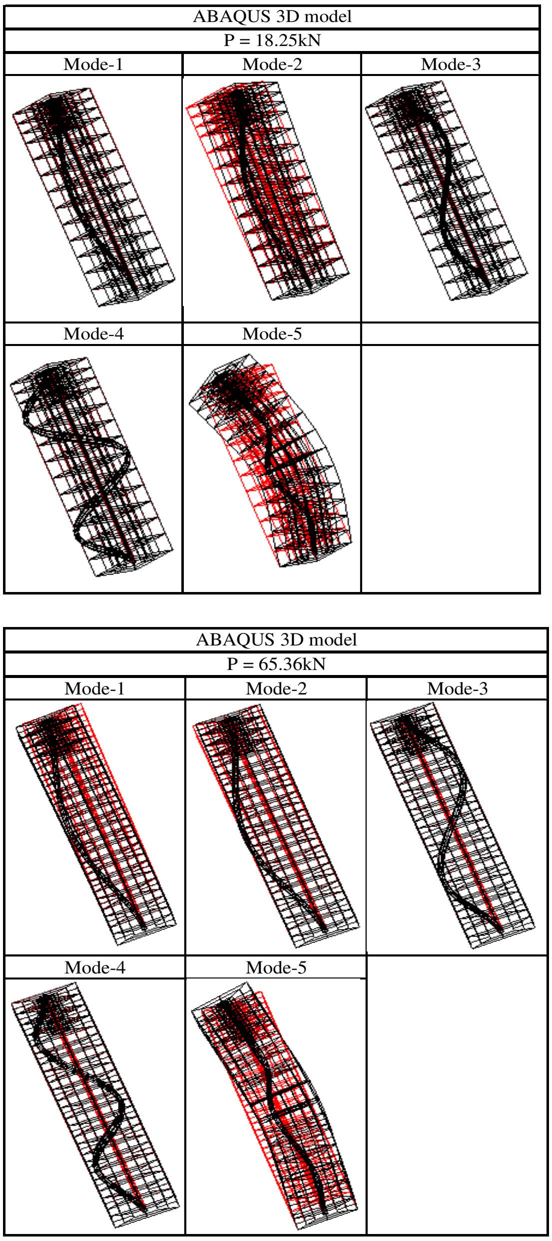


Figure 8. Mode shapes of a post-tensioned masonry column, ABAQUS 3D Model

Natural frequency comparisons between the ABAQUS 2D and 3D models are given in Table 8 and Figure 9. Very similar results were given from the two models. The same behaviour was shown by both 2D and 3D models for the natural frequency and post-tension force relations with ABAQUS 2D results being typically bigger than the ABAQUS 3D results by between 0.5% and 5.0%.

Results of mode shape of ABAQUS 2D and 3D models were also similar. For the post-tension force of 18.25kN, the first, third and fourth modes were dominated by the post-tensioning bar behaviour and the second and fifth modes by the column behaviour. For the post-tension force of 65.36kN, the first modes started to be dominated by the column behaviour. The second, third and fourth modes were dominated by post-tensioning bar behaviour. The fifth modes were still dominated by the column behaviour.

Table 8. Natural frequency differences between ABAQUS 2D and 3D Models

	ABAQUS				
Post-tension	**(2D-3D)/3D (%)**				
force (kN)	**f_1**	**f_2**	**f_3**	**f_4**	**f_5**
0.00	4.57	0.66	4.38	4.02	4.90
18.25	4.21	0.87	4.36	4.06	4.90
32.79	3.60	1.39	4.35	4.08	4.90
40.60	3.02	1.93	4.34	4.10	4.90
65.96	1.20	3.70	4.34	4.14	4.90
101.39	0.66	4.20	4.35	4.21	4.89
134.94	0.57	4.28	4.35	4.31	4.82
156.55	0.55	4.30	4.37	4.55	4.62
184.83	0.53	4.32	4.38	4.82	4.39
219.96	0.51	4.34	4.41	4.87	4.39
252.20	0.51	4.37	4.43	4.88	4.42
275.99	0.50	4.38	4.45	4.88	4.45

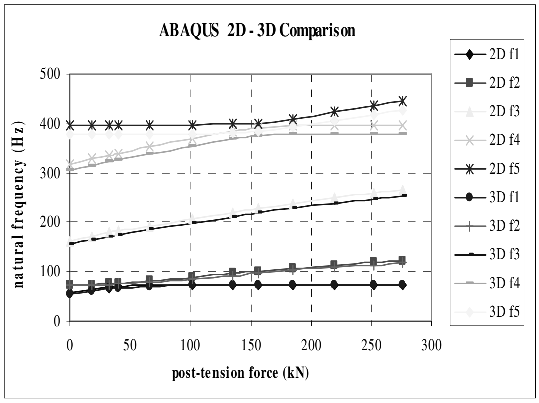


Figure 9. Comparison between natural frequencies ABAQUS 2D and 3D Models

Comparison between LUSAS and ABAQUS results

A comparison of the results between LUSAS and ABAQUS would allow a better understanding on the validity and precision of the numerical analysis. The comparison is detailed in the following sections.

2D Model comparison

A comparison between LUSAS and ABAQUS analyses on the natural frequencies of the post-tensioned masonry column obtained using 2D models is shown in Table 9 and Figure 10.

Table 9. Natural frequency differences between 2D Models ABAQUS and LUSAS

2D MODEL					
Post-tension force (kN)	(ABAQUS-LUSAS)/LUSAS (%)				
	f_1	f_2	f_3	f_4	f_5
0.00	-0.11	0.61	-0.26	-0.39	4.59
18.25	-0.04	0.53	-0.24	-0.36	4.58
32.79	0.08	0.38	-0.22	-0.34	4.57
40.60	0.18	0.26	-0.22	-0.33	4.56
65.96	0.39	0.00	-0.20	-0.27	4.51
101.39	0.37	-0.05	-0.18	-0.04	4.28
134.94	0.30	-0.06	-0.17	1.67	2.52
156.55	0.25	-0.06	-0.16	3.38	0.84
184.83	0.19	-0.07	-0.15	4.25	0.00
219.96	0.11	-0.06	-0.14	4.41	-0.16
252.20	0.03	-0.07	-0.14	4.44	-0.19
275.99	-0.02	-0.07	-0.13	4.44	-0.19

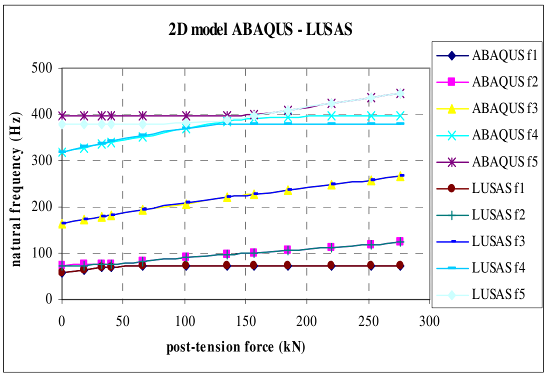


Figure 10. Comparison between natural frequencies 2D Models ABAQUS and LUSAS

The two programs produced remarkably similar results. Natural frequency differences of 2D ABAQUS to LUSAS were between -0.4% and +5.0% with the biggest differences occurring for the fourth natural frequency at higher post-tension forces and the fifth natural frequency at lower post-tension forces.

Similar mode shape results were revealed using the two programs. For a post-tension force of 65.36kN the first mode shapes were dominated by the column behaviour and the second mode shapes were dominated by the post-tensioning bar behaviour.

3D Model comparison

Table 10 and Figure 11 show the comparisons of the 3D analysis results for natural frequencies of the post-tensioned masonry column obtained from the two software packages used. It can be seen that the results obtained were of the same order and very similar. Natural frequency differences of 3D ABAQUS and LUSAS were between -1.4% and +0.7 %. Most results from ABAQUS were less than those from LUSAS. The elements chosen for modelling using the two programs use gave the closed results.

Table.10. Natural frequency differences between 3D Models ABAQUS and LUSAS

3D MODEL					
Post-tension force (kN)	(ABAQUS-LUSAS)/LUSAS (%)				
	f_1	f_2	f_3	f_4	f_5
0.00	0.67	-0.20	0.34	-0.19	-1.34
18.25	0.56	-0.18	0.29	-0.22	-1.34
32.79	0.45	-0.13	0.25	-0.24	-1.33
40.60	0.37	-0.07	0.23	-0.25	-1.33
65.96	0.01	0.22	0.18	-0.29	-1.33
101.39	-0.14	0.29	0.11	-0.35	-1.32
134.94	-0.16	0.26	0.06	-0.45	-1.25
156.55	-0.16	0.23	0.02	-0.75	-0.98
184.83	-0.16	0.18	-0.02	-1.17	-0.59
219.96	-0.16	0.14	-0.07	-1.26	-0.54
252.20	-0.16	0.09	-0.12	-1.28	-0.56
275.99	-0.15	0.07	-0.15	-1.28	-0.59

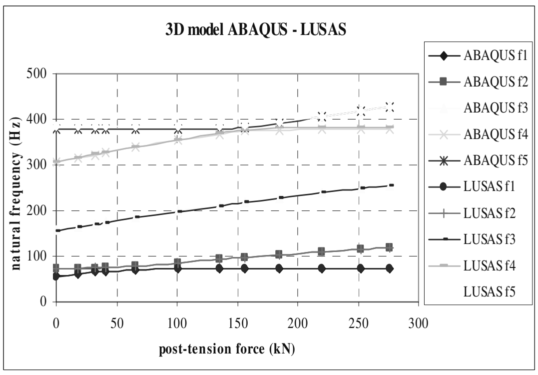


Figure 11. Comparison between natural frequencies 3D Models ABAQUS and LUSAS

CONCLUSIONS

Some conclusions can be drawn as follows:

1. Natural frequencies of post-tensioned masonry column comprise the natural frequencies of its components which are masonry column and post-tensioning bar. With increasing post-tension force the natural frequencies increased.
2. The differences in natural frequencies of 2D and 3D models for LUSAS and ABAQUS were insignificant. They were between -1.0% and +5.0%, and all 2D results were in general higher than 3D results.
3. The natural frequency results of ABAQUS to LUSAS results were between -1.4% and +5.0%. Most results showed that those from ABAQUS were generally smaller than LUSAS results. Any of the two programs can be used to predict natural frequency of post-tensioned masonry column with the appropriate chosen elements.
4. The comparison studied indicates that it is suitable and accurate to use 2D model to predict natural frequency and mode shape of masonry column using any of the computer package program.

RECOMMENDATION

The quality of finite element computer packages to predict structural behaviour should be assured. Verification to the theoretical or experimental studies is of important.

REFERENCES

Chan, C.F. (2000). *Effect of Prestress Force on the Vibration and Stability of Beams*. MSc Dissertation, UMIST.

Hibbit, H.D. Karlsson, B.I., and Sorensen, E.P. (1998). *ABAQUS Version 5-8*, Finite Element Program. Hibbit, Karlsson, & Sorensen, Inc., Providence, R.I.

LUSAS 13.4. Finite Element Analysis Ltd. Surrey, United Kingdom.

Mandal, P and Ji, T. 2004. Modelling dynamic behaviour of a cantilever grandstand. *Proceedings of the Institution of Civil Engineers. Structures and Buildings*. 157. Issue SB3,173-184.