M-P Curves for Strengthened Concrete Columns With Active Confinement

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ABSTRACT:
Many existing reinforced concrete buildings suffer from lack of strength and ductility against lateral loads, especially earthquake load, due to design style based on old codes. Such buildings should be strengthened and retrofitted to comply with new loading and design requirements. Confinement of concrete is an effective and commonly used method in strengthening of columns. Confining of concrete increases compressive strength of concrete and enhances the ductility. Passive and active confinements are two methods for confining of concrete. In this study, effect of active confinement on axial and bending capacity of strengthened concrete columns using steel angle profiles is investigated and M-P curves are illustrated. Stress-strain curve of confined concrete is obtained using Drucker-Pruger model of ANSYS. This curve is modified to a parabolic curve; then is used for determination of bending moment-axial load (M-P) diagrams of aforementioned strengthened concrete columns. The diagrams are drawn for specific square columns with different reinforcement ratios and different compressive strength of concrete. These diagrams highlight the effectiveness of the method used for achievement of confinement of concrete columns.

KEYWORDS: Reinforced concrete structures, Active confinement, M-P curves.

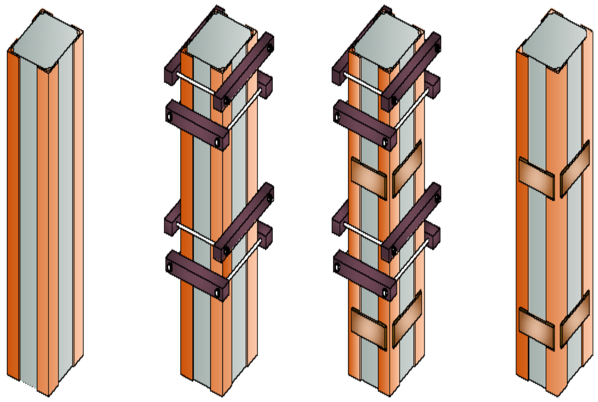
1. INTRODUCTION

There are many reasons for strengthening of concrete columns; among them it can be referred to differences in old codes especially in respect to earthquake load, changes in the vertical loads, deficiencies in the construction, etc. Confining of concrete columns is one of the most important procedures which has been used by many researchers and engineers from many years ago. The reason is that we can get strength and ductility improvement in concrete with confinement techniques

In general, there are two different methods for confining concrete. In the first method which is known as passive confinement, lateral expansion is limited by confining concrete with some elements such as steel jackets or FRP sheets; therefore tension axial forces are created in these confining elements. The increase of axial load in the column in this case increases the degree of confinement. Close stirrups in concrete columns also provide a kind of passive confinement. The stirrups limit lateral expansion of concrete leading to tensile stress in stirrups. Efforts have been done to present a numerical model for the effects of stirrups in confinement of concrete. Among these researches, it can be referred to researches done by Richart et al., Ahmad et al., Mander et al., Kent and Park, Sheikh and Uzumeri and Saatcioglu et al. Each researcher presents an equation for stress-strain relationship of confined concrete. Many researchers also studied the effects of confinement provided by FRP wraps on compressive capacity, bending capacity and stress-strain curve of concrete.

In the second method of confinement which is famous as active confinement, from the beginning of confinement, a primary lateral pressure is applied on column. Near Surface Mounted (NSM) technique is a sample of active confinement. In this method, FRP reinforcement is pre-tensioned and then glued in a groove that was made in the column. The pre-tensioning here provides a primary confinement pressure in concrete.

In the current study, active confinement method is used to strengthen the rectangular concrete columns. Four angles are put in the corners of columns and confining pressure is applied by fastening bolts. This method is illustrated in Fig. 1. Fig. (1-a) shows the concrete column with four angles on the corners. It can be seen in Fig. (1-b) that bolts are passed inside the thick plates and by fastening bolts, lateral pressure is exerted. As it is shown in Fig. (1-c), some plates are welded in the space between two thick plates and finally as it is shown in Fig. (1-d), the bolts are opened and put aside.



(a) (b) (c) (d)

Figure 1 Method of strengthening the concrete column in this research

In the current study, by modeling of confinement in ANSYS software, stress-strain curves for strengthened columns are obtained, and then by using MATHEMATICA software, M-P curves are drawn for 400 mm squared concrete columns with different longitudinal reinforcement ratios and three types of compressive strengths.

2. THE CURRENTLY APPLIED MODELS FOR DEFINING CONCRETE CONFINEMENT

In general, if the lateral pressure f_l is performed in a reinforced concrete member such as a column, the compressive strength of confined concrete (f'_{cc}) is obtained according to Eq. (1); where f'_c is the compressive strength of unconfined concrete, and k is coefficient of confinement.

$$f'_{cc}=f'_c+k f_1 \qquad (1)$$

In finite element modeling of a confined concrete member, researchers usually use Drucker-Prager model (Mirmiran, Barros and Abdesselam). To incorporate the model, concrete compressive strength (f'_c) and k are taken as functions of two parameters (c and φ) and are obtained from Eq. 2. Many researches have been done to determine k. Here, we adopted Eq. (3) to determine k, which is suggested by Saatcioglu et al.

$$f'_c=\frac{2c\text{譪}os\varphi}{1\text{-}\sin\varphi} \qquad k=\frac{1+\sin\varphi}{1\text{-}\sin\varphi} \qquad (2)$$

$$k=6.7?\ f_1)^{-0.17} \qquad (3)$$

To define the confinement, in the analysis, Drucker-Prager model of ANSYS software is used. First, k is calculated from Eq. (3), then φ and c coefficients are calculated from Eq. (4), which is obtained by manipulating Eq. (2).

$$\varphi=\sin^{-1}\left(\frac{k\text{-}1}{k+1}\right) \qquad c=\frac{f'_c\,(1\text{-}\sin\varphi)}{2\cos\varphi} \qquad (4)$$

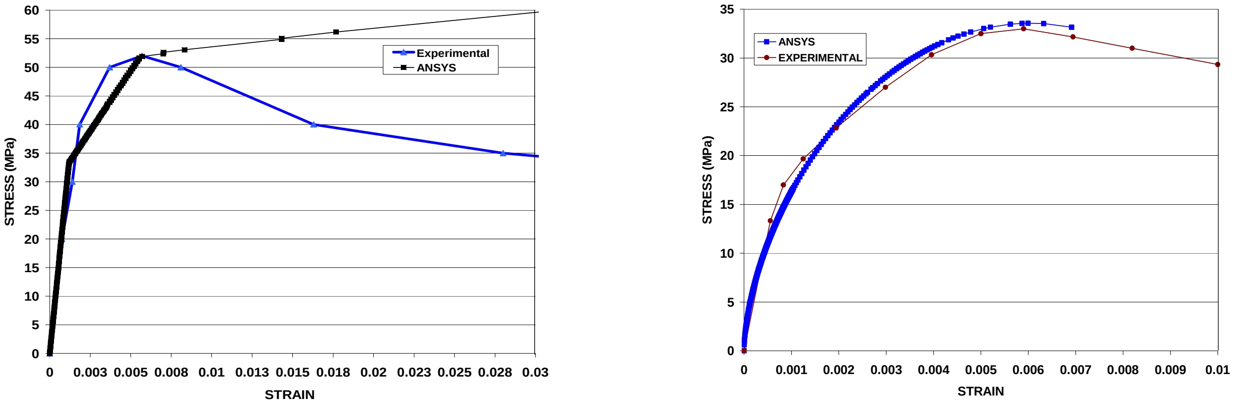
3. CAPABILITY CONTROL OF DRUCKER-PRAGER MODEL FOR MODELING CONFINEMENT

To assess the capability of Drucker-Prager model for confinement modeling, two samples are analyzed in

ANSYS software. The samples are exactly the same as the experimental specimens used by Mander. Finally, the stress –strain curves of the current analysis and the experimental diagrams are compared.

3-1. Cylindrical Sample Under Pure Pressure

The cylindrical sample is a circular column with 500 mm diameter and the height of 1500 mm with 8 longitudinal reinforcement with diameter of 28mm and lateral reinforcement of 12 mm diameter at spaced at 52 mm. The ultimate strength of concrete is 32 MPa and the ultimate strength of steel is 340 MPa. The sample was under uniaxial pressure and modeled by ANSYS soft. The plasticity behavior of confined concrete was modeled by Drucker-Prager model and the confinement was exerted by the lateral reinforcement. The c and φ coefficients are calculated using Eq. (4). The comparison between experimental and FEM results are presented in Fig (2-a). The following remarks can be calculated from Fig. (2-a):



(a)

(b)

Figure 2- Comparing the results obtained from software and the laboratory test

1- Maximum stress of experimental model coincided with point of the second branch of FEM model; this fact shows that Drucker-Prager model can point out the peak of stress-strain curves of confined concrete.
2- Drucker-Prager model is not able to predict the descending branch of stress-strain relation.
3-Usually FEM model has a bilinear stress-strain relationship. If this behavior is approximated by a parabola, it will coincide with the experimental model.

3-2. Cubic Sample under Pure Pressure

This sample is a square column with 400 mm diameter and the length of 1200 mm which was under uniform displacement in laboratory. The plastic behavior of confined concrete was modeled by Drucker-Prager model and the confinement was exerted by lateral reinforcement. The c & φ coefficients are calculated using Eq. (4). The comparison between the experimental and FE results are presented in Fig. (2-b). The figure shows the capability of the suggested FE modeling procedure in ANSYS to predict ascending branch of stress-strain behavior of the sample with good accuracy.

4- M-P INTERACTION CURVES

As mentioned before, the aim of this research was to draw the M-P curves for columns which are strengthened with angle. The specimen which is investigated in this part is a square column with a cross section of 400 mm × 400 mm with 15 mm × 15 mm chamfer in corners. To strengthen the specimens, 80 × 80 × 80 angle profiles are used. To account for the chamfers, the confining pressure is exerted on 65 mm of the corners, varying from 1 to 5 MPa on different models. If the lateral pressure which is exerted to the angle is f_l, the effective lateral pressure on column side, f_{le}, is calculated from Eq. (5). In this part, it is assumed that the column is loaded up to one-half of its ultimate capacity before strengthening. As mentioned before, drucker-prager model is used for modeling the behavior of confined concrete; so for calculating c and φ coefficients Eqs. (2), (3) and (4) are used.

$$f_{le}=f_l ? \frac{2? \ 5}{400}=0.325f_l \tag{5}$$

The FE analysis of the column is done through displacement control. The strain corresponding to the confined concrete compressive strength, ε_{0c}, is calculated from Eq. (6), suggested by Razvi and Saatcioglu; where ε_{0c} in Eq. (6a) is the strain in unconfined concrete corresponding to the compressive strength. Then, the compressive strength of confined concrete, f'_{cc}, is obtained from the calculated stress-strain curve of core concrete, being corresponded to ε_{0c}. The calculated ε_{0c} and f'_{cc} are shown inn Table 1 based on the three compressive strengths of concrete as f'_c=21, 25 and 30 MPa.

$$\varepsilon_{0c}=\varepsilon_0(1+5k_1) \tag{6a}$$

$$k_1=\frac{k f_{le}}{f'_c} \tag{6b}$$

Table 1- Amount of f'_{cc} and ε_{0c} obtained from nonlinear analysis

f'_{cc}	ε_{0c}	f'_c	f'_{cc}	ε_{0c}	f'_c	f'_{cc}	ε_{0c}	f'_c	f_l
36.8	0.0029	30	31.0	0.0027	25	27.0	0.0029	21	1
38.3	0.0035		33.1	0.0034		28.3	0.0036		2
39.6	0.004		35.8	0.0040		30.6	0.0043		3
40.8	0.0045		36.0	0.0045		32.0	0.005		4
43.7	0.005		38.0	0.0051		33.65	0.0056		5

It was observed earlier that the FE modeling procedure used in this study leads to a bilinear stress-strain relationship for the confined concrete. The stress-strain curve is approximated with a parabola, using the famous Hognestad 's parabola as expressed in Eq. (7).

$$f_c=f'_{cc}\left[\frac{2\varepsilon}{\varepsilon_{0c}}-\left(\frac{\varepsilon}{\varepsilon_{0c}}\right)^2\right] \tag{7}$$

Using the obtained stress-strain relationship for confined concrete, a program was written in MATHEMATICA software to obtain the couple bending mements and axial loads, M and P, at failure of confined column. The M-P diagrams are illustrated in Figs. 3 through 5. The diagrams can be used as design charts for strengthening purposes.

5- CONCLUSION

As concluding remark, this study showed that design charts can be drawn for strengthened square-section concrete columns with confining pressure of steel angle profiles at the corners. Available FE-based software like ANSYS can be used for this purpose. The nonlinear FE analysis procedure is to be based on suitable models for plasticity of concrete; where, Drucker-Prager model can be incorporated in the analysis to account for plasticity.

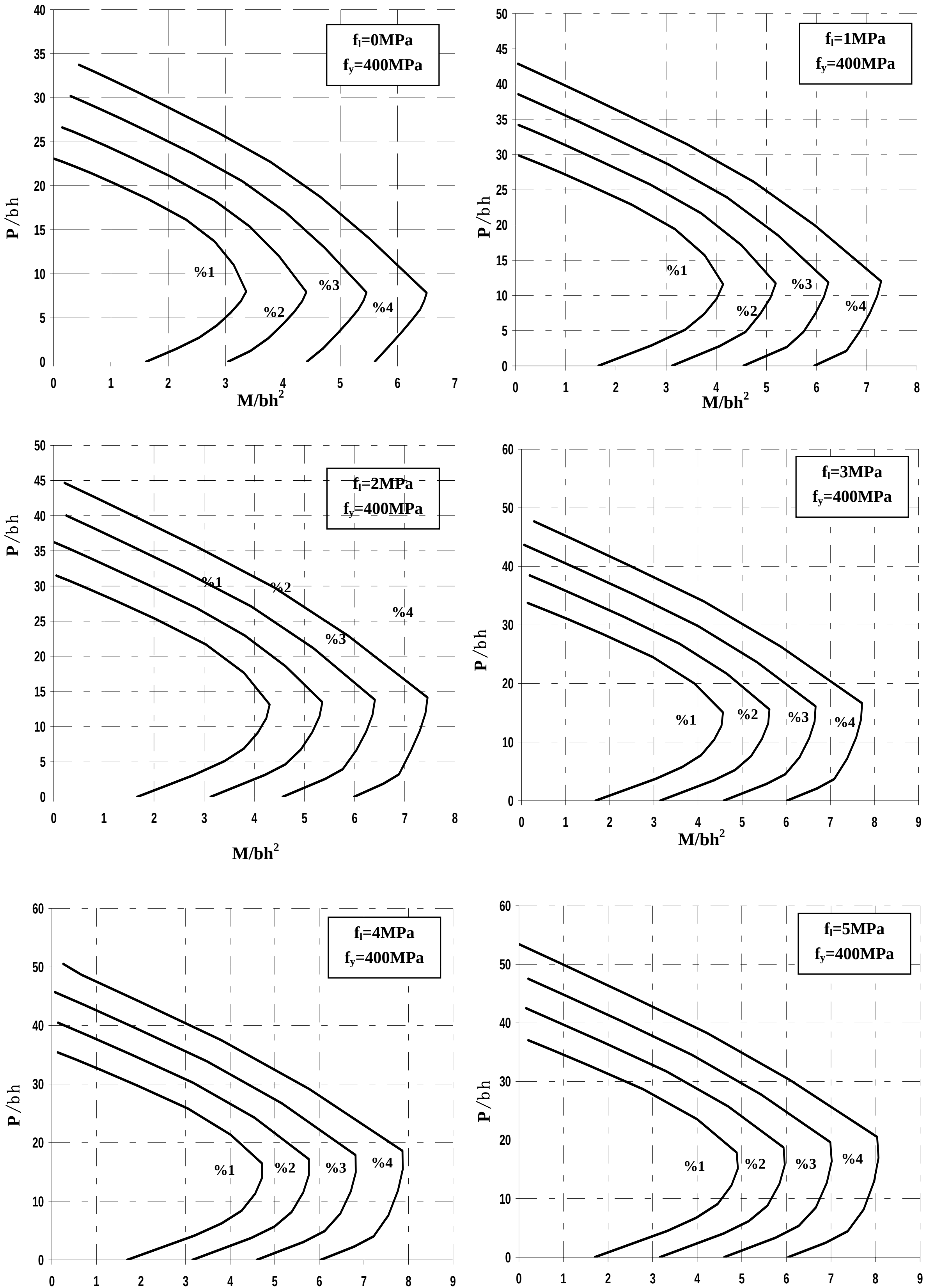


Figure 3- M-P curves for column with f'_C=21MPa

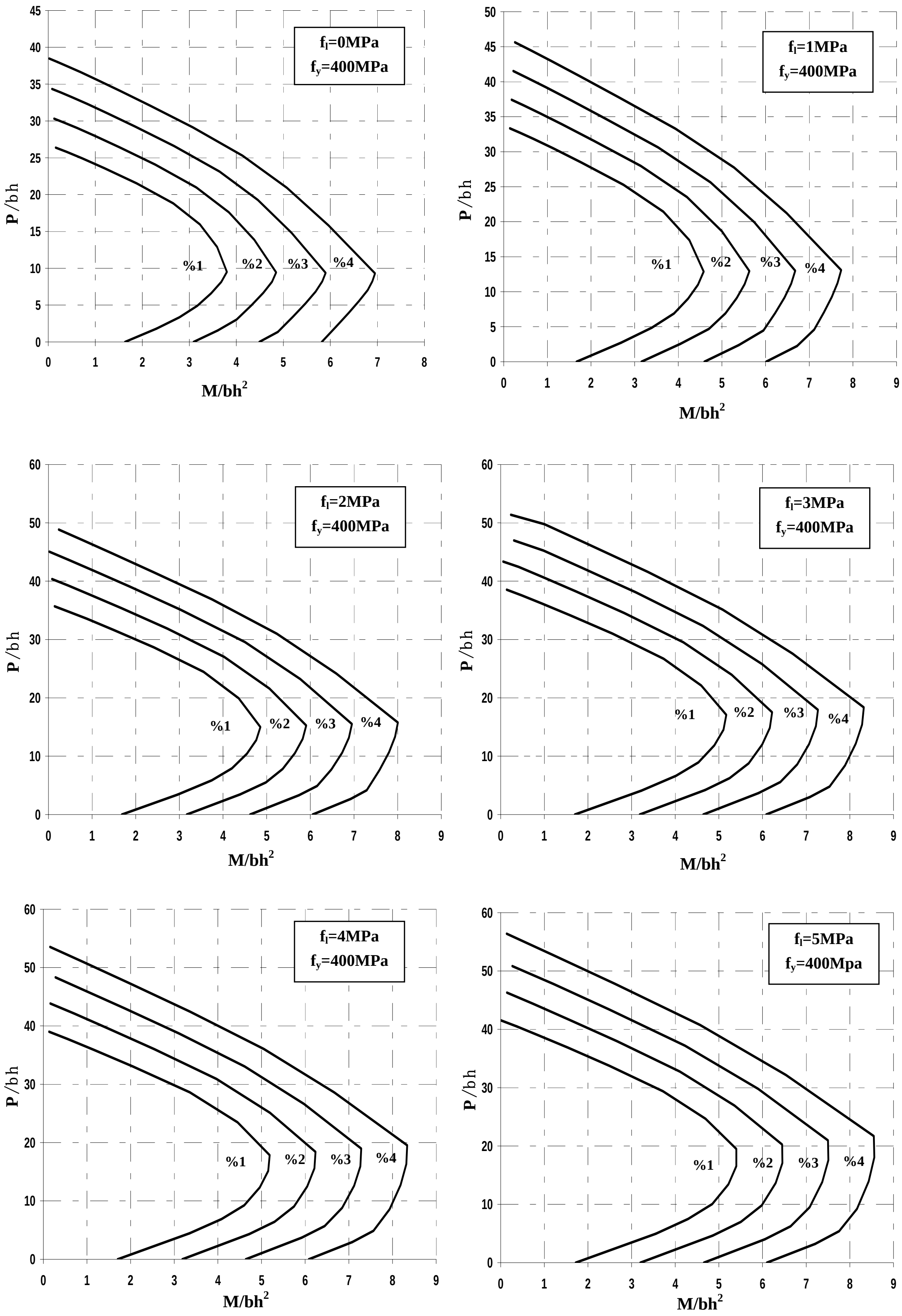


Figure 4- M-P curves for column with $f'_C=25\,\text{MPa}$

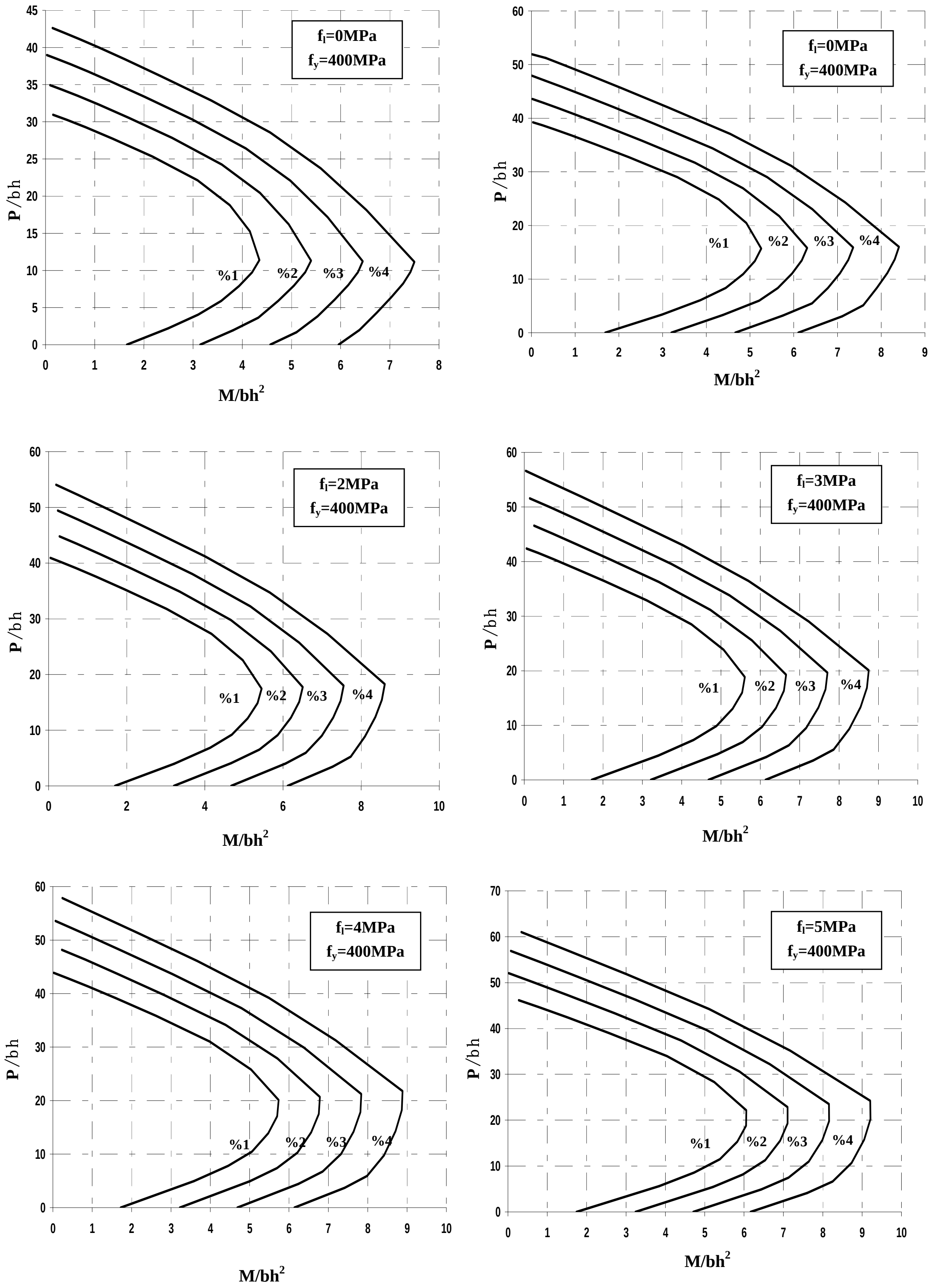


Figure 5- M-P curves for column with f'_C=30 MPa

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