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Linear Interactive and Elasto-Plastic Analysis of Plane Frame Combined Footing Soil System- A Parametric Study

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Abstract: The finite element analysis has been carried out considering the effect of soil structure interaction on two dimensional frame structure resting on combined footing subjected to pseudo static wind load. An independent analysis has been carried out for structure assuming the column has been rigid (non – interactive with lateral + vertical loading). A linear interactive analysis (with lateral+ vertical loading) of the structure has been carried out to understand the effect of soil structure on behavior of super structure. A Elasto-Plastic interactive analysis has been carried out using Drucker-Prager model in a non-linear elastic state for the soil.
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Index Terms— Bending Moments, Contact Pressure, Interactive, Settlement, Multi-linear, Windload, Elasto-Plastic .

1 Introduction

An analyst or a designer is mainly concerned with the analysis and design of variety of structures. All these structures are exclusively supported by soil and hence the subject of soil structure interaction has come into existence. The settlement, contact pressure and bending moment in the elastic combined footing are affected by the structural stiffness, type of connection between the columns and combined footing and the compressibility of sub-soil.

The solution of the problem of interaction of a frame foundation and soil mass needs a proper physical idealization. Studies indicate that beam bending elements for the frame members and plane finite element for the soil mass have been adopted. In almost all the analysis the soil mass has been treated as behaving linearly elastically, the plane frame combined footing soil system cannot be classified as a plane stress or a plane strain problem except for some specific problems such as long framed buildings on raft foundations which are idealized as plane strain problems. The earlier investigators such as King and Chandrashekaran(4), King and Yao(5) described the superstructure member including foundation beam by conventional beam element with three degree of freedom per node and used linear plane strain element to model the soil medium.

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The soil mass discretization was carried out up to a certain distance and truncated. This type of idealization is a combination of matrix and finite element methods. Noorzaei (9) used isoparametric beam bending element with three degrees of freedom per node to idealize the members of super structure including the foundation coupled finite and infinite element.

2 PHYSICAL MODELING

In the present work, Beam3 beam bending element with two nodes having one intermediate point with three degrees of freedom per node have been used to idealize member of super-structure including the foundation beam. Plane 82 element with 8 nodes having two degrees of freedom per node had been used for discretization of soil medium under plane strain conditions. ANSYS software package has been used for carrying out the analysis. In order of explore the effect on interaction on the entire behavior of three compatible units (structure-foundation-soil mass), a plane frames supported by combined footing has been taken up.

The geometric detail and material properties of the structural members and foundation are summarized in Table I and II and physical modeling for Finite Element Analysis has been shown in Fig 1.

Table 1:
Material Properties

Sl. No.	Component	Elastic modulus (kN/m²)	Poisson's ratio	Cohesion (kN/m²)	Friction angle	Flow angle
1	Structural	2.89×10^7	0.3	-	-	-
2	Wall	5×10^5	0.16	-	-	-
3	Soil mass	1×10^6	0.25	20	34	4

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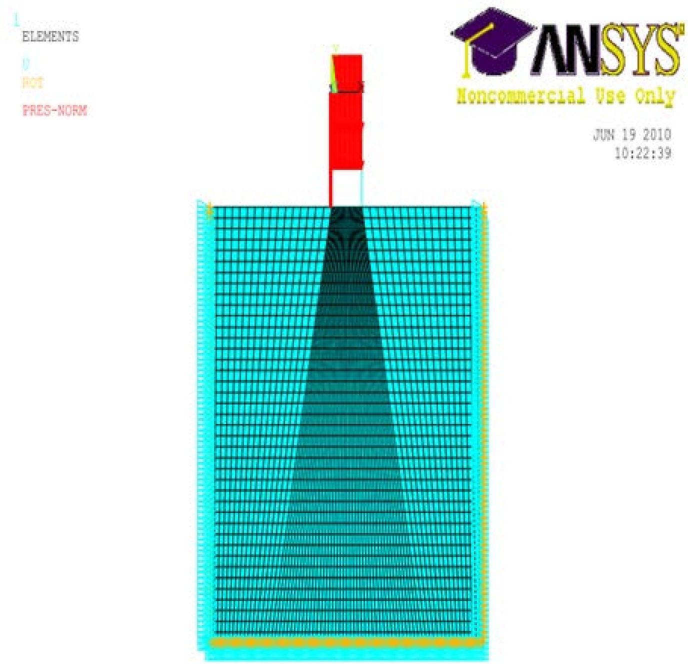

Fig 1: Linear interaction analysis of plane frame (without wall)-combined footing–soil system.

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Table 2:
Various Plane Frames Considering in the Present Analysis

Sl No	Notation	Description
1	A	1- Bay, 3- storey plane frame
2	B	2- Bay, 3- storey plane frame
3	C	3- Bay, 2- storey plane frame
4	D	3- Bay, 3- storey plane frame
5	E	3- Bay, 4- storey plane frame
6	F	3- Bay, 5- storey plane frame
7	G	5- Bay, 3- storey plane frame
8	H	5- Bay, 5- storey plane frame

2.1. Drucker – Prager Modeling:

An approximation to the Mohr–Coulomb law was presented by Drucker and Prager (1952) as a modification of the Von Mises yield criterion. The influence of the hydrostatic stress component on yielding was introduced by inclusion of an additional term in the Von Mises expression as

$$\alpha J_1 + (J_2')^{\frac{1}{2}} = K, \qquad (1)$$

where α and K are the material constants, which may be related to Coulomb's material constants c and Ø. J1 and J2′ are, respectively, the first stress invariant and the second stress invariant of the deviatoric stress components. In a three-dimensional principal stress space, the Drucker–Prager criterion can be matched with the apex of the Mohr–Coulomb criterion and either points, such as A (external cone) or B (internal cone), on its π-plane as indicated in Fig. 2 In the former case (external cone), the cone circumscribes the hexagonal pyramid, and the material constants α and K are obtained as (Zienkiewicz, 1983)

$$\alpha = \frac{2 \sin \emptyset}{\sqrt{3}(3 - \sin \emptyset)}, \qquad (2a)$$

$$K = \frac{6c \cos \alpha}{\sqrt{3}(3 - \sin \emptyset)} \qquad (2b)$$

The latter case results in an inner cone, and corresponding constants are

$$\alpha = \frac{2 \sin \emptyset}{\sqrt{3}(3 + \sin \emptyset)}, \qquad (3a)$$

$$K = \frac{6c \cos \emptyset}{\sqrt{3}(3 + \sin \emptyset)} \qquad (3b)$$

The geometrical representation of the Mohr–Coulomb and Drucker–Prager yield surfaces in principal stress space and π-plane is shown in Figs. 7.4a and b, respectively.

However, since the values of c and Ø are determined by using conventional tri-axial compression tests, these are different from those determined under plane strain condition. Under this condition, the values of α and K can be rewritten as

$$\alpha = \frac{2 \sin \emptyset}{\sqrt{3}(3 - \sin \emptyset)}, \qquad (4a)$$

$$K = \frac{6c \cos \emptyset}{\sqrt{3}(3 - \sin \emptyset)}. \qquad (4b)$$

The two material parameters α and K for the Drucker–Prager model can be determined from slope and intercept of failure envelope plotted on the J1 and J2′1/2 space, as shown in Fig. 2. When α=0 (i.e., Ø=0), this surface reduces to Von Mises surface (Fig. 7.5b).

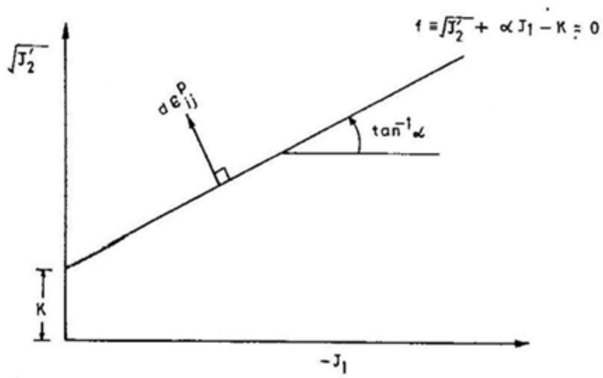

Fig . 2. Drucker–Prager yield criterion in terms of stress invariants.

3.Results:

3.1 Influence of Type of Soil on Different Parameters with Variation in Number of Bays

The non-linear interactive behaviour of plane-frame combined footing-soil system has been discussed with respect to settlement, contact pressure beneath the foundation, bending moments in super structure and displacement in X- direction of the super structure.

3.2 Maximum Bending Moment in Beams:

The relation between the number of storeys and the maximum bending moment in beam for non-interactive, linear interactive and elasto-plastic interactive analysis is shown in Fig. 3. In the case of without wall panel, it is observed that the increase in the number of storey's increases the maximum bending moments in beams up to third storey and decreases afterwards in non-interactive and linear interactive analysis. But, in the case of elasto-plastic interactive analysis, the bending moment in beams gradually increases. Whereas, in the case of with wall panel, the increase in the number of storey's gives increase in maximum bending moments in beams for non-interactive, linear and elasto-plastic interactive analysis.

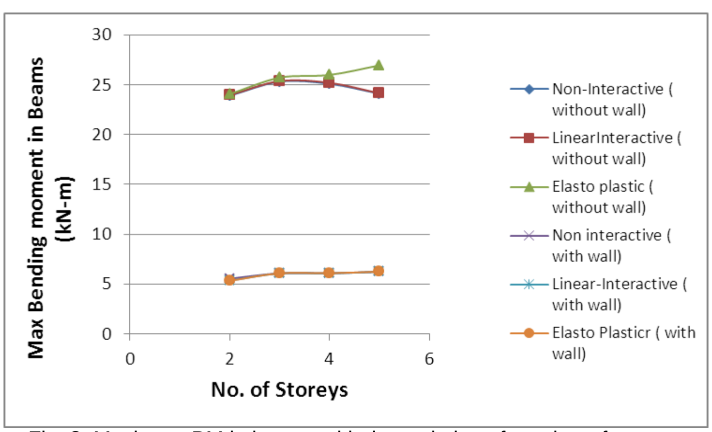

Fig. 3. Maximum BM in beams with the variation of number of storeys

3.3 Maximum Bending Moment in Columns:

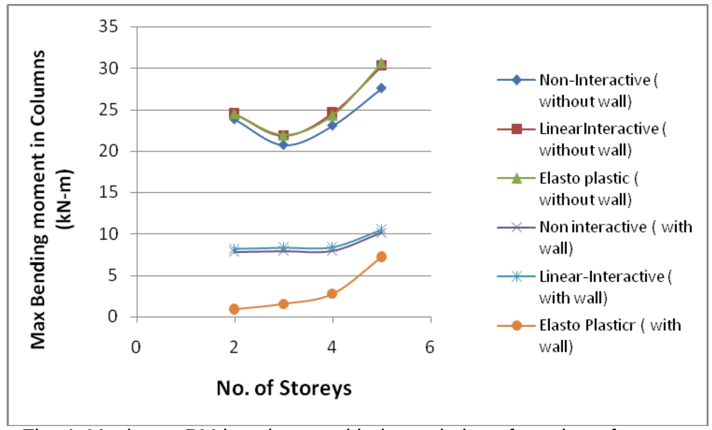

Fig. 4. Maximum BM in columns with the variation of number of storeys

The relation between the number of storeys and the maximum bending moment in column for non-interactive, linear interactive and elasto-plastic interactive analysis is shown in Fig. 4. In the case of without wall panel, it is seen that as the number of storeys increases, the maximum bending moment in column also decreases gradually in non-interactive analysis, linear interactive and elasto-plastic interactive analysis up to third storey afterwards follows a steadily increasing trend as storey increases in non-interactive analysis, linear interactive analysis and nonlinear interactive analysis. Whereas, in the case of with wall panel, the increase in the number of storeys gives increase in maximum bending moments in columns for non-interactive and linear interactive analysis. But, in the case of elasto-plastic interactive analysis, the maximum bending moment in column decreases gradually up to four storeys afterwards increases gradually.

3.4 Maximum Settlement of Footings:

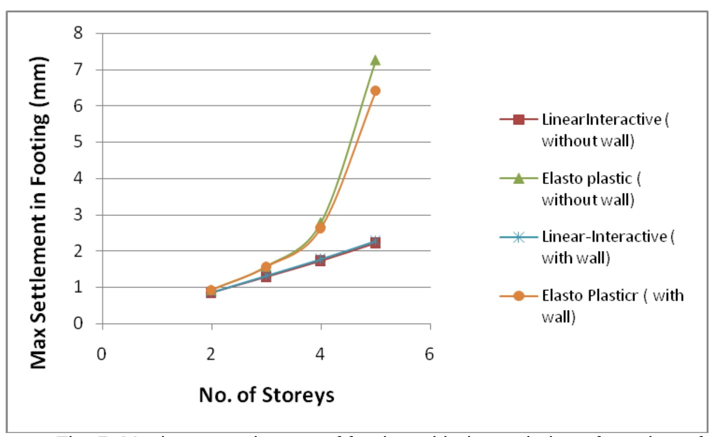

Fig. 5. Maximum settlement of footing with the variation of number of storeys

From Fig. 5 it is observed that the maximum settlement increases as the number of storeys increases in the superstructure.

The maximum settlement is observed to occur at one of the end columns in the combined footing. This can be attri-

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buted to the fact the corresponding loads at the edges are more. Due to lateral loads, settlement at the right edge of footing is more. However, the difference in settlement of footings in the case of interaction analysis is not much, because the interaction takes care of relative displacements. In both without and with wall panels, the maximum settlement in footing increases as the number of storeys increases.

3.5 Maximum Displacement of Frames in X-direction:

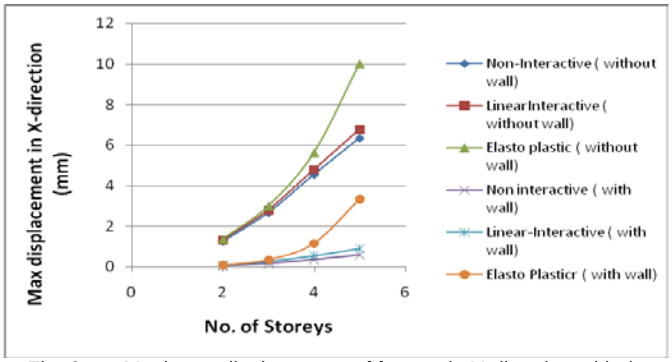


Fig. 6. Maximum displacement of frames in X-direction with the variation of number of storeys

From Fig. 6 it is observed that as the number of storeys increases, the displacement in the superstructure tends to increase in non-interactive, linear interactive and nonlinear interactive analysis with and without wall panel. This can be attributed to the fact that as the number of storeys increases, the stiffness in the superstructure decreases with and without wall panel.

3.6 Maximum Contact Pressure Below Combined Footing:

The influence of interactive analysis on maximum contact pressure below footing with the variation of the number of storeys is shown in Fig. 7. It is observed that the variation of contact pressure increases as the number of storeys increases in linear interactive analysis with and without wall panel. But, in elasto-plastic interactive analysis, the variation of contact pressure increases gradually up to four storeys without wall panel and up to third storey with wall panel afterwards gradually the variation of contact pressure decreases in both without and with wall panels.

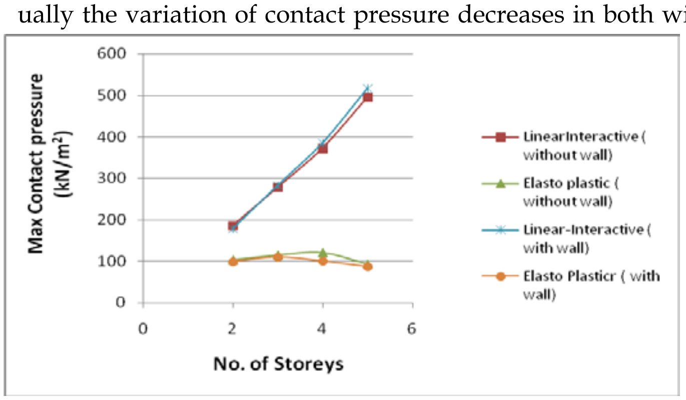


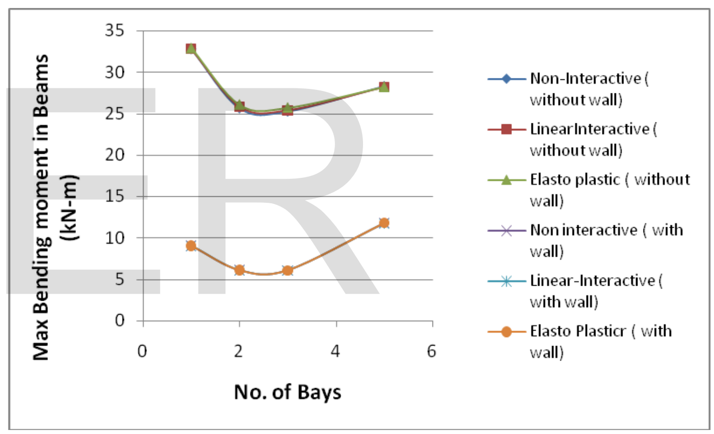
Fig. 7. Maximum contact pressure below footing with the variation of number of storeys

3.7 Influence of Type of Soil on Different Parameters with Variation in Number of Bays:

One of the objectives of the present investigation is to carry out the interactive analysis of the plane frame-combined footing–soil system by considering the nonlinear elasto-plastic analysis of the soil (material nonlinearity). The interactive behaviour of this plane frame-combined footing–soil system has been discussed with respect to settlement, contact pressure beneath the foundation, bending moments in superstructure and displacement in the X-direction of the superstructure.

3.8 Maximum Bending Moment in Beams:

The relation between the number of bays and the maximum bending moment in beams for non-interactive, linear interactive and elasto-plastic interactive analysis is shown in Fig. 8. It is observed that the increase in the number of bays gives decrease in maximum bending moments in beams up to third bay and increases afterwards for non-interactive, linear interactive and elasto-plastic interactive analysis for both without and with wall panels.



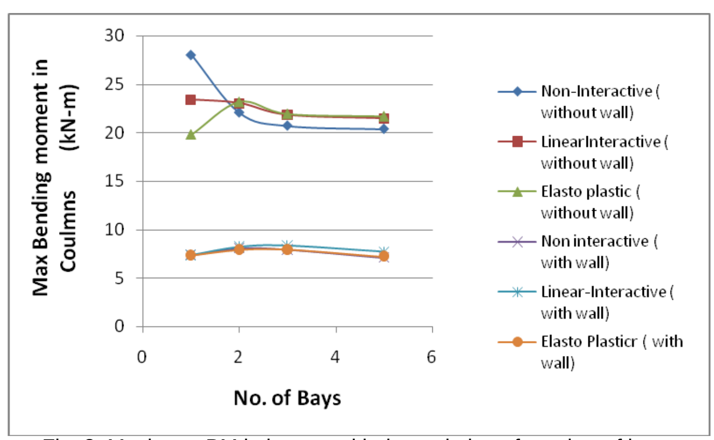


Fig. 8. Maximum BM in beams with the variation of number of bays

3.9 Maximum Bending Moment in Columns:

Fig. 9. Maximum BM in columns with the variation of number of bays

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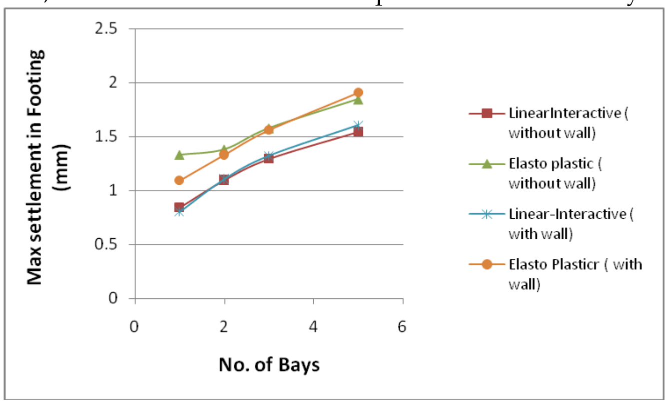
From Fig. 9 it is observed that in the case of without wall panel as the number of bays increases the maximum bending moment in column decreases gradually in non-interactive and linear interactive analysis. But, in the case of nonlinear interactive analysis, the maximum bending moment in column increases gradually up to second bay afterwards gradually decreases as the bay increases. Whereas, in the case of with wall panel, the increase in the number of bays gives increase in maximum bending moments in columns for non-interactive, linear and elasto-plastic interactive analysis up to third bay afterwards gradually decreases as the bay increases in interactive, linear interactive and elasto-plastic interactive analysis.



3.10 Maximum Settlement of Footings:

Fig. 10. Maximum settlement of footing with the variation of number of bays

The effect of interaction on settlement of footings is found out using finite element method technique, and the modified settlements of the footings are tabulated. The maximum settlement is observed to occur at one of the end columns in the combined footing. This can be attributed to the fact that the corresponding loads at the edges are more due to lateral loads, and settlement at the right edge of footing is more. However, the difference in settlement of footings in the case of interaction analysis is not much, because the interaction takes care of relative displacements. In both without and with wall panels, the maximum settlement in footing increases as the number of bays increases.

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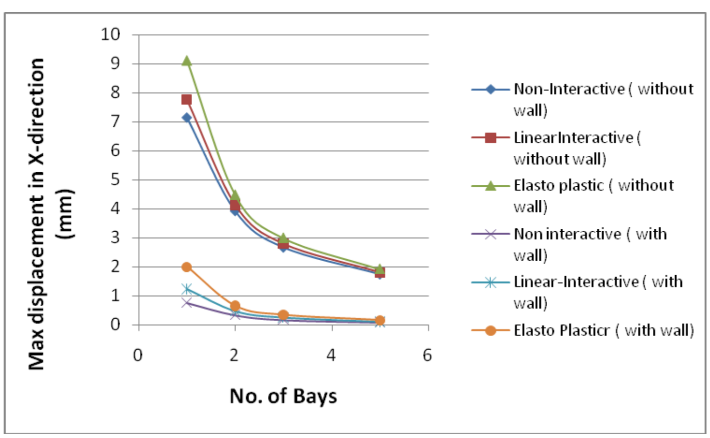

3.11 Maximum Displacement of Frames in X-direction:

Fig. 11. Maximum displacement of frames in X-direction with the variation of number of bays

From Fig.11 it is observed that as the number of bays increases, the displacement in the superstructure tends to decrease in non-interactive, linear interactive and elasto-plastic interactive analysis with and without wall panel. This can be attributed to the fact that as the number of bays increases, the stiffness in the superstructure increases with and without wall panel.

3.12 Maximum Contact Pressure Below Footing:

The influence of interactive analysis on maximum contact pressure below footing with the variation of the number of bays is shown in Fig. 12. It is observed that the variation of maximum contact pressure decreases steadily in linear interactive and nonlinear interactive analysis in without wall panel. Whereas, in the case of with wall panel, the maximum contact pressure decreases steadily with increase in the number of bays in nonlinear interactive analysis. But, in the case of linear interactive analysis with wall panel, the maximum contact pressure decreases steadily up to second bay afterwards steadily increases as the bay increases.

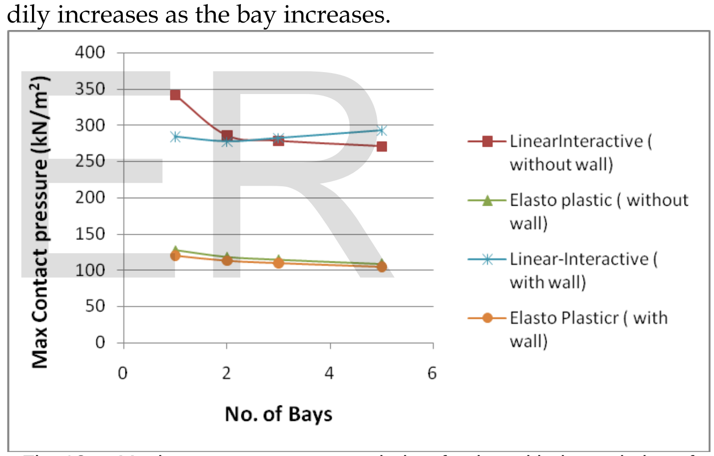

Fig. 12. Maximum contact pressure below footing with the variation of number of bays

4. Conclusion:

The present work is concerned with the study of nonlinear soil–structure interaction of the plane frame-combined footing–soil system with and without wall panel by considering them as a single integral compatible unit using finite element method. Based on the limited parametric study carried out, the following conclusions have been drawn.

4.1 Elasto-Plastic Interactive Analysis:

1. It may be concluded that the increase in the number of storeys increases the maximum bending moments in beams up to third storey by 5% in non-interactive, 23% in linear interactive and 12% in elasto-plastic analysis without wall panel and increases in beams by 13% in non-interactive, 16% in

linear interactive and 17% in elasto-plastic analysis with wall panel. It may be concluded that the increase in the number of bays gives decrease in maximum bending moments in beams up to third bay by 32% in non-interactive, 32% in linear interactive and 32% elasto-plastic analysis afterwards increases by 93% in non-interactive, 92% in linear interactive and 93% in elasto-plastic analysis with wall panel.

2. It may be concluded that, without wall panel, the increase in the number of bays gives decrease in maximum bending moments in beams by 22% in non-interactive, 22% in linear interactive and 21.8% in elasto-plastic analysis without wall panel afterwards increases by 11% in non-interactive, 11% in linear interactive and 9.6% in elasto-plastic analysis.
3. It may be concluded that in the case of without wall panel as the number of bays increases, the maximum bending moment in column decreases by 27.7% in non-interactive, 8% in linear interactive and elasto-plastic analysis, increases up to second bay 17% and further gradually decreases with and without panel.
4. It may be concluded that in both without and with wall panels the maximum settlement in footing increases as the number of storeys increases.
5. It may be concluded that in both without and with wall panels the maximum settlement in footing increases as the number of bays increases.
6. It may be concluded that as the number of storeys increases, the displacement in the X-direction of the superstructure tends to increase in non-interactive, linear interactive and also elasto-plastic interactive analysis with and without wall panel.
7. It may be concluded that as the number of bays increases, the displacement in the X-direction of the superstructure tends to decrease in non-interactive, linear interactive and elasto-plastic interactive analysis with wall panel and without wall panel.
8. It may be concluded that the variation of contact pressure increases as the number of storeys increases in linear interactive analysis with wall panel and without wall panel. But, in nonlinear interactive analysis, variation of contact pressure increases gradually up to four storeys in without wall panel and up to third storey in with wall panel afterwards gradually variation of contact pressure decreases in both without and with wall panels.
9. It may be concluded that the variation of maximum contact pressure decreases steadily in linear interactive and nonlinear interactive analysis in without wall panel. Whereas, in the case of with wall panel, the maximum contact pressure decreases steadily with increase in the number of bays in nonlinear interactive analysis. But, in the case of linear interactive analysis with wall panel, the maximum contact pressure decreases steadily up to second bay afterwards steadily increases as the number of bays increases.

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