Linear Soil-Structure-Interaction Effect on the Columns of an Unsymmetrical Plane Frame for Different Types of Soil

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***Abstract*: The foundation of a multi-storey building resting on a settable soil mass undergoes differential settlement which changes the forces in the beams and columns significantly. The multi-storey buildings, it is necessary to consider seismic forces for analysis. The building frame, foundation and soil mass are considered to act as single, compatible structural unit. The strain-stress characteristics of soil mass are responsible for differential settlement which redistributes the forces in the superstructure. In the present work, the linear interaction analysis of an unsymmetrical eight storey plane building frame-homogeneous soil system under seismic loading has been carried out for different types of soil. It is a comparative study of the redistribution of forces of the building frame for the soils having different elastic constants. ANSYS software is used as a tool for finite element analysis of the frame and soil model.**

Keywords: conventional frame analysis, linear interaction analysis, finite element method, plane frame, soil-structure interaction, linear analysis.

I. INTRODUCTION

In the conventional analysis of a building frame the foundation loads are calculated without considering soil settlement. In this type of analysis the structure is assumed as perfectly flexible structure. But this assumption may give unrealistic and uneconomical solution. The strain-stress characteristics of soil mass are responsible for differential settlement. A small differential settlement may also change the forces of the structural members. It is necessary to consider building frame, foundation and soil as single integral compatible structural unit for real analysis of the system.

Finite element method is a powerful tool for numerical analysis of any soil-structure interaction problem. The problem under investigation is discretized using the ANSYS software which solves the structures using finite element method.

II. LITERATURE REVIEW

The interaction behavior of plane frames with an elastic foundation having normal and shear moduli of sub grade reactions is studied by Aljanabi et al. [1].

The efficiency of coupled finite-infinite elements formulation with respect to computational effort, data preparation and the far field representation of the unbounded domain is investigated by Noorzaei [2].

Al-Shamrani and Al-Mashary [3] presented a simplified procedure for the analysis of soil structure interaction behavior of 2-D skeleton steel or reinforcement concrete frame structure resting on isolated footing.

Roy et al. [4] performed an analysis on 3-D frame structure with grid foundation.

The effect of soil structure interaction on an space frame resting on a pile group embedded in the cohesive soil (clay) with flexible cap is examined by Chore el al. [5]

Guzman [6] concluded that when a strap footing is used as part of a foundation system, a detail that allow for pressure to be relieved from the strap beam is necessary on construction documents.

ANSYS finite element code is compared by Thangaraj and Ilamparuthi. [7]

The stress and settlement distribution of a tank foundation by using the software ANSYS is studied by Xiujuan et al. [8]

Halkude S.A., Kalyanshetti M.G. and Barelikar S.M.(2014) judge the seismic response of R.C. Frames with raft footing considering soil structure interaction. [9]

The effect of horizontal stress & displacements in loaded raft foundation are studied by Swami Rajashekhar et al. [10]

A review on soil-structure interaction behavior of structure-foundation-soil system is carried out by Vivek Garg and M. S. Hora. [11]

Garg and Hora (2012) carried out interaction analysis of a three-bay three-storey RCC space frame 9footing-strap beam-soil system using ANSYS software. [12]

R.K. Agrawal and M.S. Hora (2011) carried out nonlinear interaction analysis of plane frame-homogeneous soil system under seismic loading. [13]

III. PROBLEM UNDER INVESTIGATION

In the present study, a three bay eight storey RC unsymmetrical plane building frame has been considered to investigate the linear soil-structure interaction behaviour of the frame-soil interaction system subjected to lateral seismic forces. The building height of 23.0m and base width of 16.0m resting on soil media having different elastic properties is used for conventional and linear interaction analysis. Seismic zone V is considered for calculating seismic forces. The equivalent seismic lateral force method is used to evaluate the seismic forces.

The complete details of the problem under investigation are shown in Figures 1. Table I shows the geometrical properties of the super structure and soil. Table II shows the material properties of the concrete and Table III shows the elastic constants of the various types of soil.

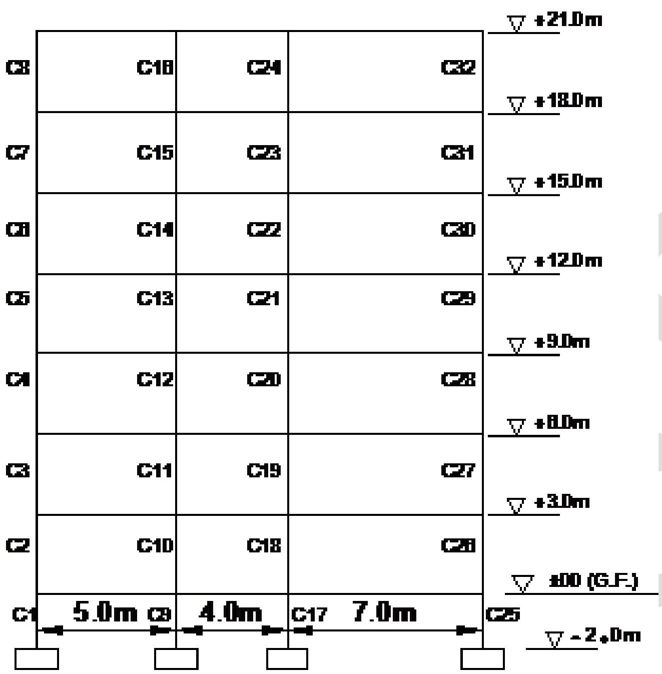

Fig. 1. Geometrical details of frame under analysis

TABLE I

Geometrical Properties of the Super Structure

S. No.	Structural components	Properties and size of components
1	All floor and plinth beam	0.30m x 0.50
2	Columns	0.50m x 0.50m
3	Footings	3.0m x 3.0m x1.0m
4	Number of bays	3
5	Number of storeys	08
6	Floor beam and plinth beam uniformly distributed loading	40 kN/m
7	Depth of soil	10.0 m

TABLE II

Material Properties of Concrete

	Property	Value
1	Grade of concrete for all structural members	M-25
2	Modulus of elasticity of concrete (N/mm2)	Ec = 5000√fck
3	Poisson's ratio of concrete	0.17
4	Density of concrete	25000 N/m^3

TABLE III

Soil Elastic Constants

Soil Type	Soil Designation	Modulus of elasticity (kN/m^2)	Poisson ratio
Hard	E-65	65000	0.3
Medium Hard	E-35	35000	0.4
Soft	E-15	15000	0.4

IV. LOADING ON FRAME

The floor beams and plinth beams carry total uniformly distributed load of 40 kN/m as the dead load and live load. The seismic force is calculated for seismic zone V of India. The seismic loads have been calculated by static method as per IS 1893 (Part-I):2002 considering seismic zone V. The parameters used for calculation of seismic forces are given in the Table IV and estimated seismic forces are provided in Table V.

TABLE IV

Parameters used for Estimation of Seismic Forces.

S. No.	Parameters/ Particulars	Value/Type
1	Seismic Zone	V
2	Seismic Intensity	Severe
3	Zone factor	0.36
4	Type of soil	Medium
5	Importance factor	1.0
6	Type of building	Moment resisting
7	Response reduction factor	5.0

TABLE V

Seismic Forces at Various Floor Levels

S. No.	Floor Level	Seismic Force (kN)
1	Foundation level (-2.00m)	00
2	Ground Floor (00)	0.922
3	I (+3.00 M)	6.912
4	II(+6.00 M)	17.971
5	III (+9.00 M)	34.099
6	IV (+12.00 M)	55.296
7	V (+15.00 M)	82.022
8	VI (+18.00 M)	113.357
9	VII (+21.00 M)	149.760

V. FINITE ELEMENT ANALYSIS

The modelling and analysis of the problem is achieved using ANSYS software which has a number of elements and material models suited for the problem under consideration. Table VI shows the different elements used for descritization of different structural elements.

TABLE VI

Different Types of Elements used for Descritization

S. No.	Structural elements	Element Name
1	Column	Beam188
2	Beam	Beam188
3	Footing	Solid65
4	Soil mass	Solid65

A. Conventional Frame Analysis (CFA):

The conventional analysis of plane frame is carried out without considering the structure-soil interaction. The combination of dead load, live load and seismic load (DL+LL+EL) is considered for analysis. Figure 2 shows the descritized model of building frame.

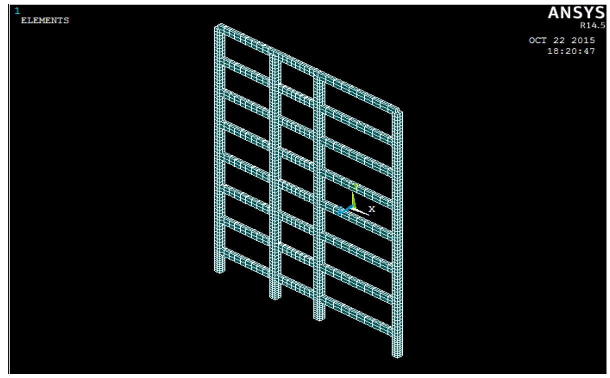

Fig. 2. Descritized model of Building Frame used in CFA

B. Linear Interaction Analysis (LIA):

The linear interaction analyses of the plane frame-soil system for the different soil media are carried out assuming the structure, footing and soil to act as a single compatible structural unit and to behave in linear elastic manner. In this also the combination of dead load, live load and seismic load (DL+LL+EL) is considered for analysis.

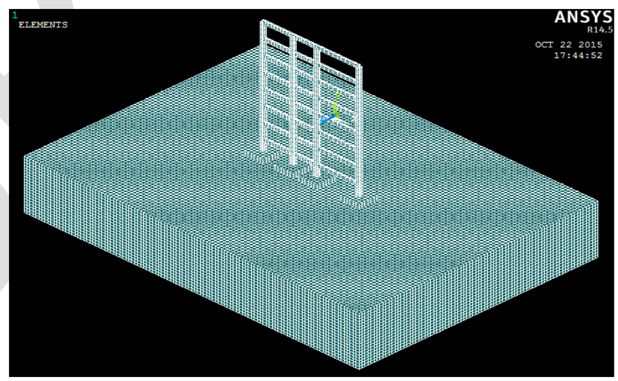

Fig. 3. Descritized model of Building Frame and soil used in LIA

VI. RESULT AND DISCUSSION

The results of the conventional frame analyses and linear interaction analyses for different soil media are compared to investigate the following;

- Axial forces on the columns
- Bending moment on the columns

The results are discussed to highlight the effect of various soil media of different elastic constants when the linear soil-structure interaction is considered. Thus, the comparative results of axial forces and bending moments are tabulated for the columns C1 to C32 in the Table VII and VIII respectively. Due to interaction effect, differential settlements take place in the footings, which results in redistribution of axial forces and moments in the columns. Figures 4-7 shows the comparative results of axial forces in the columns located at various floors.

TABLE VII

Comparative results of Axial Forces in the Columns

S. No.	Column Position	Column No.	Axial Force (kN)			
			CFA	LIA		
				E-65	E-35	E-15
1	Left End Columns	C1	282.78	356.8	422.3	542.3
		C2	247.11	347.45	404.5	508.1
		C3	237.13	328.0	376.2	463.7
		C4	227.01	302.4	341.9	413.7
		C5	210.79	270.2	301.2	357.6
		C6	184.3	227.8	250.5	291.7
		C7	142.59	170.2	184.7	210.9
		C8	79.80	91.2	97.2	108.1
2	Left Interior column	C9	1273.6	1206.6	1173.4	1107.8
		C10	1118.0	1069.5	1039	979.7
		C11	967.56	929.0	903.3	853.3
		C12	817.18	785.2	764.0	722.9
		C13	664.25	639.1	622.4	590.2
		C14	507.64	489.4	477.3	454.0
		C15	346.07	334.9	327.5	313.0
		C16	177.42	173.8	171.1	165.7
3	Right Interior column	C17	2109.7	1934.7	1837.1	1666.0
		C18	1834.8	1664.8	1582.1	1438.2
		C19	1547.8	1398.4	1328.6	1207.0
		C20	1263.3	1140.7	1083.7	984.1
		C21	986.13	889.9	845.0	766.7
		C22	718.88	648.2	615.2	557.7
		C23	464.60	418.8	397.5	360.2
		C24	228.17	207.5	197.9	181.0
4	Right End Columns	C25	1455.9	1621.9	1687.2	1803.9
		C26	1280.1	1398.2	1454.3	1554.0
		C27	1087.5	1184.6	1231.9	1316.0
		C28	892.56	971.6	1010.4	1079.3
		C29	698.83	760.9	791.3	845.5
		C30	509.18	554.7	577.0	616.7
		C31	326.74	356.0	370.3	395.8
		C32	154.61	167.5	173.9	185.1

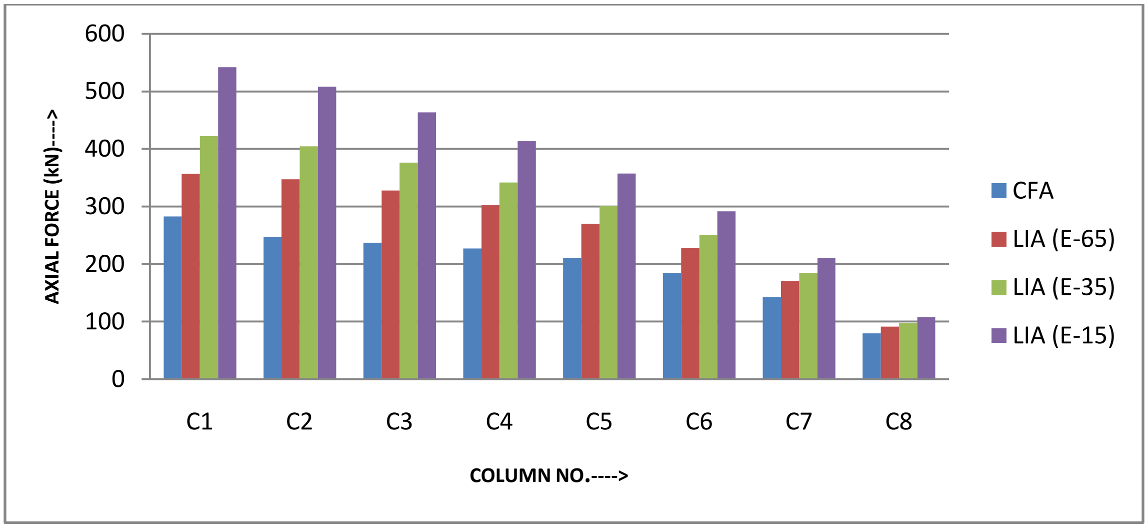

Fig. 4 Comparative Chart of Axial Forces in the Left End Columns

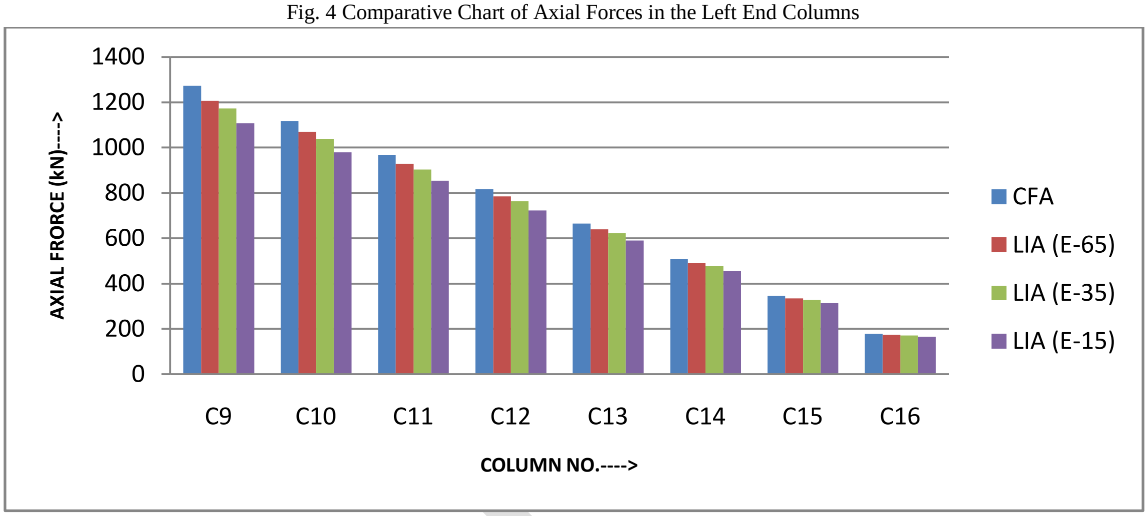

Fig. 5 Comparative Chart of Axial Forces in the Left Interior Columns

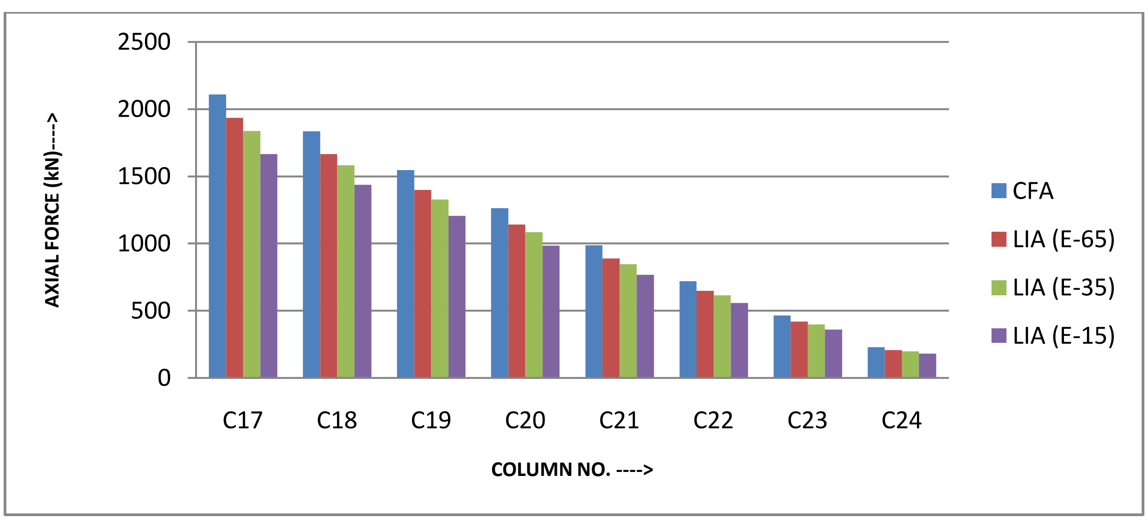

Fig. 6 Comparative Chart of Axial Forces in the Right Interior Columns

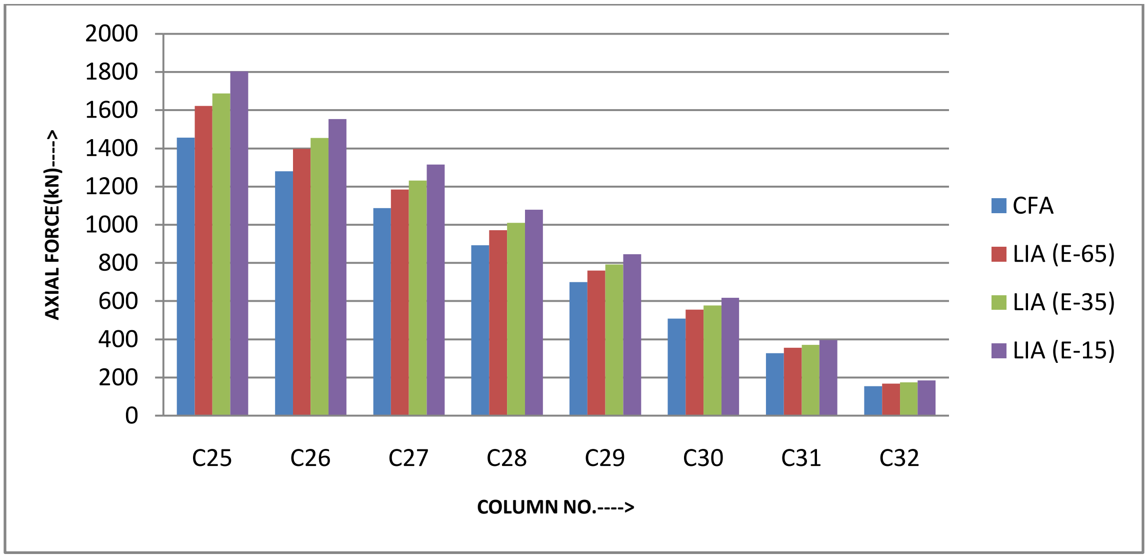

Fig. 7 Comparative Chart of Axial Forces in the Right End Columns

TABLE VIII

Comparative results of Bending Moments in the Columns

S. No .	Column Position	Column No.	Bending Moments (kN-m)							
			CFA		LIA					
					Soil (E-65)		Soil (E-35)		Soil (E-15)	
			Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom
1	Left End Columns	C1	-150.7	-28.47	6.25	118.8	6.34	120.5	6.2	117.6
		C2	-109.27	62.98	-39.9	65.0	-21.5	53.8	9.0	33.9
		C3	-79.25	74.25	-57.4	59.5	-48.4	49.8	-31.7	32.2
		C4	-68.71	73.41	-48.6	55.4	-38.6	45.8	-20.4	28.2
		C5	-55.27	67.86	-36.7	49.8	-27.1	40.3	-9.6	23.1
		C6	-36.45	57.51	7.5	39.6	-8.7	30.3	8.5	13.4
		C7	-10.8	45.18	7.4	27.9	16.9	18.9	34.0	2.6
		C8	26.41	-14.16	45.7	-40.5	55.8	-54.2	73.9	-78.9
2	Left Interior column	C9	-195.2	82.80	11.5	219.1	10.1	192.7	7.4	140.5
		C10	-231.06	197.34	-227.3	218.0	-221.6	207.9	-213.2	190.6
		C11	-221.0	214.23	-188.9	193.8	-175.3	181.5	-151.2	159.7
		C12	-205.52	207.8	-181.5	185.0	169.8	173.4	-449.0	152.9
		C13	-184.18	192.45	-160.4	169.4	-148.8	158.1	-128.2	137.9
		C14	-153.08	168.67	-99.3	145.9	-118.7	134.8	-98.6	114.9
		C15	-108.3	128.76	-85.7	107.1	-74.5	96.5	-54.8	77.6
		C16	-56.22	89.41	-31.3	58.4	-19.1	43.2	2.5	16.2
3	Right Interior column	C17	-169.6	18.53	42.5	269.0	14.9	282.6	16.2	308.0
		C18	-166.5	132.70	-161.3	182.7	-167.1	191.0	-178.3	206.6
		C19	-157.74	152.61	-171.3	173.6	-180.5	182.4	-196.9	198.4
		C20	-146.18	150.22	-161.6	167	-169.8	175.4	-184.9	190.8
		C21	-129.26	139.52	-144.9	155.5	-153.1	163.8	-168.2	178.9
		C22	-102.21	118.7	-117.7	134.4	-125.8	142.6	-140.6	157.5
		C23	-65.03	93.0	-80.43	108.25	-88.5	116.2	-103.1	130.6
		C24	-6.40	18.76	-22.2	39.3	-30.5	50.0	-45.7	69.6
4	Right End	C25	-183.7	56.60	14.1	267.6	14.7	278.8	16.24	308.6
		C26	-194.8	146.20	-155.4	190.8	-172.4	205.2	-196.7	230.1

	Columns	C27	-162.4	160.2	-186.9	190.5	-199.9	204.0	-223.6	228.0
		C28	-157.2	164.16	-183.0	191.2	-196.1	204.3	-219.3	227.6
		C29	-148.9	163.74	-174.7	189.8	-187.4	202.5	-210.0	225.2
		C30	-135.5	159.8	-160.9	185.2	-173.3	197.7	-195.5	219.9
		C31	-115.43	143.9	-140.5	168	-152.9	179.8	-174.8	200.8
		C32	-96.26	177.90	-122.3	217	-135.2	236.2	-158.0	270.3

VII. RESULT AND DISCUSSION

a) The axial forces and bending moments in the columns of the frame due to interaction effect for different soil media is considerably different from the conventional frame analysis.

b) As the modulus of elasticity of the soil decreases, significant increase in the axial forces is found in the end columns (left and right), whereas the decrease in the axial forces is found in the interior columns.

c) As the modulus of elasticity of the soil decreases, the interaction effect causes a significant decrease in bending moments of the left side columns (end and interior both), whereas a significant increase in bending moments is found in right side columns.

d) The variation in the axial loads of left end columns is more than the right end columns and interior columns.

e) The elastic properties of soil significantly affect the interaction analysis results of a building frame.

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