SHUTTLE TECHNIQUE FOR SOIL-STRUCTURE INTERACTION IN FRAMED STRUCTURES

TECHNIQUE NAVETTE POUR INTERACTION SOL-STRUCTURE DANS LES STRUCTURES EN CADRE

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SYNOPSIS

An attempt has been made here to present a technique for interactive analysis of plane and space frames supported by individual column footings. The method is iterative in nature and neglects transverse shear deformations in frame members. The soil is represented as a 3 D elastic half space. The technique adopts displacement approach for the analysis of frames and 3 D FEM for analysis of soil-foundation system. Interactive behaviour so obtained is compared with the experimentally observed behaviour of model plane frames installed in silty sand. The differential settlements, frame sway and strains in frame members were monitored during the variable point loading of frames. It has been found that the proposed technique is highly convergent and yields results comparable to those experimentally observed.

INTRODUCTION

In the past, many investigations have been carried out concerning some aspects of interaction of framed structures with supporting soil-foundation systems. The major problem that one has to deal with in interactive analysis is regarding the idealisation of the soil mass. Much controversy was raised over the application of winkler model as it neglects the shear strength of soil. It has, however, been recognised that winkler model can yield acceptable results, especially for large foundation slabs at the interior of which disturbing boundary conditions are negligible. The subgrade modulus depends on stress level and size and shape of the loaded area. The elastic half space theory leads to a more complex analysis but the physical representation is vastly superior to winkler model. The elastic parameters vary with the drainage conditions and their values to predict immediate and total final settlements can be obtained from laboratory triaxial tests.

EARLIER WORK

Meyerhof (1953) developed approximate methods to estimate the stiffness of structures and to relate it to the deformation characteristics of soil.

Morris (1966) defined the analysis of continuous frame resting on soil as essentially one of variable loads applied to a visco-elastic medium. Differential settlements can result as time dependent stress relaxation occurs in the loaded soil mass. The foundation forces are then redistributed and, in turn, alter the response of the structure. To couple the structure to the surface of soil mass in order to represent the time dependent action, soil-footing system was replaced by a kelvinian model in series with vertical springs. The mathematical model included a composite governing visco-elastic equilibrium equation for the complete system. The analysis neglects torsional moments and illustrates that time dependent strains can lead to various critical stress conditions.

Lee and Brown (1972) carried out a comparative study of a seven storey, three bay plane frame with combined footing due to both winkler and the elastic half space models for soil. Hain and Lee (1974) proposed a rational analysis of raft foundation on the basis of a substructure approach proposed earlier by Haddadin (1971). The same substructure approach was followed by king and Chandrasekaran (1974) for studying the interactive behaviour of rafted space frames founded on an over consolidated soil stratum.

Majid (1976) tested single storey, single bay, plane and space frame models, fabricated out of mild steel sections and supported by steel pad footings in a test bed of dry sand. The frames were subjected to gradually applied variable point loads. The observed behaviour was investigated to study the mutual interaction of structural components and the effect of differential settlements and angular distortion.

Buragohain et al. (1979) presented a fully three dimensional formulation for space frame-raft-soil system. Viladkar (1983) proposed various methods for interactive analysis of frame structures founded on isolated footings. Nayak et al. (1985) studied the effect of sequence of construction in multistoreyed building frames. The flexibility of foundation has been represented by assuming winkler model. It was observed that such a simulation leads to considerable variation in design moments as against those due to conventional one step analyusis of frame with rigid base.

PROPOSED APPROACH

Assumptions :

In this study, an attempt has been made to present a shuttle technique for the interactive analysis for both plane and space frames, supported by individual column footing-soil system (Fig. 1). The approach is based on the assumptions that transverse shear deformations, coupling of bending and the twisting moments and axial-flexural interaction are neglected. The soil below the footings is treated as a linear elastic half space and that the interference between the adjacent footing is neglected.

Steps Involved :

(i) Isolated the superstructure from the soil footing system.

(ii) Member Stiffness Matrices-compute the local stiffness matrices for various frame members depending upon whether it is a plane or a space frame.

(iii) Transformation-Transform the member stiffness matrices from the local axes to the global or structure oriented axes using the transformation matrix depending upon whether plane or space frame is being analysed. The transformed member stiffness matrices are stored sequentially on magnetic disc/tape for further use.

(iv) Overall Load Vector-Member load vectors are replaced by a statically equivalent joint load vectors to form an overall joint load rector which when added to direct joint loads vector yields a global load vector for the complete structure. This is stored on magnetic tape/disc for further use.

(v) Equation System - Force-displacement equation system for the superstructure is solved by Gaussian elimination process in half band. Such a solution gives the deformations at various joints of the frame.

(vi) Member End Actions-Compute the frame member end actions which are the forces and moments at member ends. However, if the member is a column, proceed for next step.

(vii) Foundation Analysis - The column end actions with their signs reversed would act as forces on the footing supporting this column. Analysis the soil-footing system below this structural column by three dimensional finite element procedure using either linear or parabolic brick elements. This yields settlements and rotation of the footing and the strains and stresses in the soil mass.

(viii) Store all the settlements and rotations of all the footings on the magnetic tape/disc in the form of an array. These deformations act as specified boundary conditions for reanalysis of the frame in which external load vector is treated as null.

(ix) Pick up the next member and go to step (vi) to find member end actions for all members and the deformation of all footings.

(x) Convergence Test - Compare the settlements and rotations of the footings so obtained in each cycle with those of the previous cycle. If the difference is less than the tolerance limit, stop the analysis. If the difference exceeds the tolerance limit, proceed for next step.

Step (i) to (x) form one complete iteration.

(xi) Re-analysis-Repetition of step (v) with the settlements and rotations of footings below every column incorporated as initial boundary conditions and treating external load vector as null gives new set of deformations and forces in the structure.

(xii) Repeat steps (vi) to (x) till the criterion in step (x) is satisfied.

EXPERIMENTAL WORK

A single storey, single bay model of plane frame, 1.2m high and 1.0m width, was fabricated out of mild steel bars having 25mm x 25mm cross section. Steel footing pads, 150mm x 150mm, in size were welded at the base of the frame columns. The entire assembly was installed in the field (silty sand) with a footing depth of 0.20m. The frame was loaded with a variable point load and the settlements of footing, sway of the frame and strains all along the frame at various points were measured (Fig.1). Two different tests were conducted with variable load position defined by e(the ratio of the distance of the point of load application with half the span of the frame) equal to 0.2 and 0.6 with maximum applied load of 630 kg and 1080 kg respectively.

INTERACTIVE BEHAVIOUR

The interactive behaviour of the plane frames was studied using the proposed shuttle Technique. The test plane frame (Fig.1) was analysed for two different test conditions . The soil-footing system was analysed using 3D FEM with 19 eight noded isoparameteric brick elements. The tolerance limit provided for deformations was 0.0001 mm and that for rotations, 0.0001 rad.

It has been found that the procedure is quite convergent and requires only four iterations

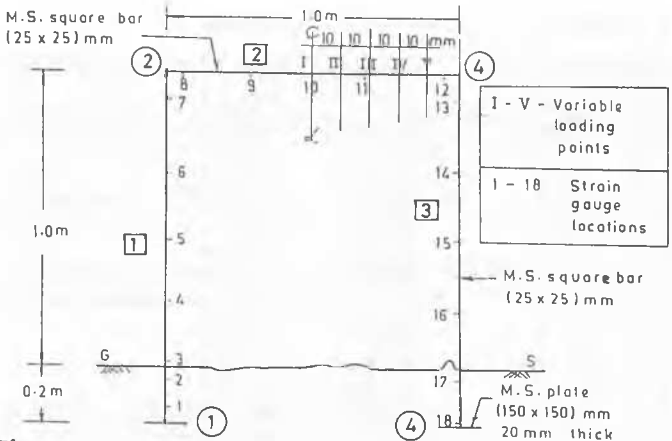

Fig. 1. - Plane frame showing load positions and strain gauges

Joint Deformations, Total and Differential Settlements and Sway of Frame :

Table-1 gives values of total and differential settlements and sway of the frame obtained at the end of convergence of the shuttle technique for the cases i.e. e = 0.2 and 0.6. The table also gives the corresponding values observed during the experimental testing of plane frame-footings-soil system. It is found that for the same load, increasing the eccentricity of load increases the settlement of the right footing and simultaneously reduces the settlement of the left footing and thus aggravates the differential settlement. It can be seen that there is a reasonably good agreement of values of settlements of the left and right footings and differential settlement. As regards sway, the values reasonably match for the case of e = 0.2. However, for e = 0.6, the experimental value of sway appears to be on the higher side. The good agreement between these values therefore suggests that shuttle technique is applicable for the analysis of problems of interaction of frame structures with supporting foundations.

Shear Forces and Bending Moments

The values of shear forces and bending moments, in various structural members, as referred to local member axes, are presented in Table-2 for the two load positions, e = 0.2 and 0.6. The table gives the values obtained on the basis of both the independent analysis (base fixity) and the cumulative values obtained at the end of convergence using the shuttle technique. At joints other than the base joints (2 and 3) it has been found that the moments obtained from independent analysis are higher than those obtained via interactive analysis. The two analyses reveal the reversal in the nature of the bending moments at the column bases (1 and 4). The base moments for the fixed base condition would give rise to non-uniform stress distribution below the footings. However, these base moments reduce in magnitude with reversal of their nature due to interaction. As the column-footing system is supported by flexible soil mass, any non-uniform stress distribution across the footings tilts them outwards and rotates the columns at joints 1 and 4 which produces high opposing moments. This relieves the excess bending moments at these joints. The change in axial forces in column is significant, however, it is insignificant in case of transverse shear forces.

CONCLUSIONS

1. The shuttle technique is basically iterative in nature and is an indirect way of accounting for the interaction.

2. A good comparison of the values of total and differential settlements and the sway obtained by the shuttle technique with the corresponding values observed experimentally suggests that this technique is applicable to problems of interaction of framed structures with soil-foundation system.

3. The technique is highly convergent in nature.

Table - 1 Total and Differential Settlements and Sway of Plane Frame

Load Position e	Applied load (kg)	Methodology	Sett. of Left footing δ_L(mm)	Sett. of Right footing δ_R(mm)	Differential Settlement δ_{DF} (mm)	Sway (mm)
0.2	630.0	Shuttle Technique	1.94	2.97	1.03	2.97
		Experimental Testing	2.15	3.32	1.70	2.75
0.6	1080.0	Shuttle Technique	1.63	6.77	5.13	5.28
		Experimental Testing	1.92	6.01	4.18	9.73

Table - 2 Shear forces and bending moments at the end of convergence

Member	Joint		F_X(kg)		F_Y(kg)		M_Z(kg-m)	
			Ind. Anal.	Int. Anal.	Ind. Anal.	Int. Anal.	Ind. Anal.	Int. Anal.
1	1	0.2	249.9	244.3	-60.4	-1.3	-26.25	30.33
	2		-249.9	-244.3	60.4	1.3	-46.92	-31.85
2	2		60.4	1.3	249.9	244.3	46.92	31.85
	3		-60.4	-1.3	380.0	385.7	-50.65	-41.34
3	4		380.0	385.7	60.4	1.3	22.52	-38.38
	3		-380.0	-385.7	-60.4	-1.3	50.65	66.28
1	1	0.6	211.1	201.6	-70.7	-4.2	-35.12	26.90
	2		-211.1	-201.6	70.7	4.2	-50.60	-31.94
2	2		70.7	4.2	211.1	201.6	50.60	31.94
	3		-70.7	-4.2	868.9	878.4	-63.69	-54.82
3	4		868.9	878.4	70.7	-4.2	22.02	-49.78
	3		-868.9	-878.4	-70.7	4.2	63.69	-54.82

Ind. Anal. - Independent (non-interactive) analysis
Int. Anal. - Interactive analysis.

4. The shear forces and bending moments due to interactive analysis are on the lower side vis-a-vis those due to independent (non-interactive) analsyis with fixity of bases.

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