practical lessons learned. In addition, more suppliers now have several projects behind them and are more experienced in identifying pitfalls and avoiding unexpected problems as well as having ironed out some early technical and software difficulties. Other users and suppliers therefore command an important body of experience and their comments and advice will be sought at an early stage by the prudent selector.

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Sequence of Construction in Multistoreyed Frames - A Time Dependent Phenomenon

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KEYWORDS

Sequence of construction, Multistoreyed two and three dimensional frames, storey by storey construction, time dependent phenomenon, design forces, soil-structure interaction.

ABSTRACT

Multistoreyed building frames are constructed in stages storey by storey. The loading pattern on the frame due to self weight of members thus follows that of accreted bodies, wherein self weight is imposed on the structure in stages as the construction proceeds. In conventional analysis, the effect of sequence of construction which leads to stage by stage imposition of dead load due to self weight of structural members and other finishing items is often neglected and it is assumed that all the design loads are imposed only after the building frame has been completed upto the roof level and has gained strength and elasticity at a standard age. Apart from this time dependent imposition of dead load, analysis of multistoreyed frames should also include the effects of other time dependent phenomena like change in stiffness of members due to differential ageing of the members and joint behaviour, creep and soil structure interaction with sequence of construction. The effect of non-homogeneous foundation conditions is quite serious even with the sequence of construction.

In this paper, the concept of incremental loading has been discussed and adopting a model of sequence of construction an eleven storeyed three bay frame has been analysed both as a two dimensional and three dimensional frame. The elastic foundation system for the frame has also been considered based on Winkler's foundation model. The results of one step analysis have been compared and certain interesting observations have been made. The effect of various parameters is highlighted. The net change in design moments is clearly brought out. The study reveals the effect of various parameters such as frame idealisation, the incremental loading, and other time dependent properties of members and joints for more accurate assessment of the member forces.

La séquence de construction des structures à plusieurs étages
Un phénomène dépendant du temps

S.C. Chakrabarti et G.C. Nayak

MOTS CLES:

Séquence de construction, Construction étage par étage, Phénomène dépendant du temps, Calcul des efforts, Interaction sol-structure.

RESUME:

Les structures des bâtiments à plusieurs étages sont construites étage par étage. Habituellement, dans l'analyse des efforts, les effets de la construction par addition étape par étape de charges telles que la structure et les autres éléments finis, sont négligés. Il est supposé que toute la charge est placée seulement après que la structure soit achevée et ait toute sa résistance et son élasticité. L'analyse des structures à plusieurs étages devrait prendre en compte les effets des phénomènes dépendants du temps tels que la variation raideur des éléments de la structure, le comportement des joints, le glissement du terrain, l'interaction sol-structure. Durant la séquence de construction, les effets de conditions non homogènes de fondations peuvent être sérieux.
Dans cette communication, le concept de charge incrémentale a été évalué. L'auteur a adopté comme modèle la séquence de construction d'une structure de onze étages à trois baies. L'analyse a été faite en considérant la stucture comme étant bi-dimensionnelle, puis tri-dimensionnelle. Le modèle d'élasticité pris pour les fondations de la structure est celui de Winkler. Les résultats pour une analyse à un niveau ont été comparés, et certaines observations intéressantes ont été faites. Ont été mis en lumière notamment, les effets de divers paramètres tels que l'idéalisation de la structure, le chargement incrémental, et d'autres phénomènes dépendants du temps concernant les éléments de structure et les joints.

INTRODUCTION

Construction of multistoreyed frame is really a time dependent phenomenon. Looking into the mode of incidence of load on multistoreyed frame, it is evident that part of the total load is applied in stages as the construction proceeds storey by storey, whereas the remaining part of it is imposed on completion of the frame. Unfortunately, this aspect of incremental loading spread over the time domain due to storey by storey construction has been overlooked till now by the engineers, although its effect on the final stresses of the frame is quite considerable.

The effect of incremental time dependent loading in conformity with layer by layer construction has been studied by various investigators for stability of slope, embankments and dams [1-3]. The results obtained were conspicuous for their variations with conventional one step analysis and the time dependent incremental loading concept in the analysis of dams and embankments has been widely accepted.

In case of multistoreyed building frame, however, the effect of sequence of construction has yet to get its due importance although some earlier studies [4-6] have indicated the importance of incremental loading concept due to sequence of construction. The authors had earlier found the effect of sequence of construction on the stress resultants in the members for a 11-storeyed frame restrained at the base [7-8].

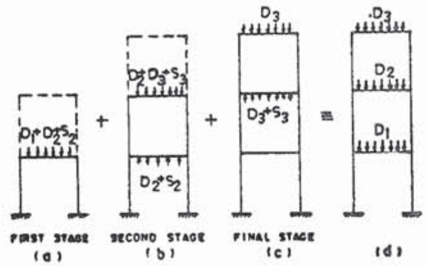
In this paper, an attempt has been made to compare the effect of sequence of construction on the final stresses in an eleven storeyed 2-D frame supported on rigid and flexible foundation and also treating the same frame as a three dimensional frame supported on rigid foundation. Analysis have been carried out by using a computer program based on stiffness matrix method.

MODELLING OF CONSTRUCTION SEQUENCE

Depending on engineering as well as socio-economic considerations, sequence of construction varies from building to building. Since occurrence of incremental loading depends on the sequence of construction planned, it has been assumed for the purpose of this study that only the concrete frame along with the structural slab is constructed in stages, storey by storey and all other items of work, e.g. filler walls, plastering, flooring are carried out once the complete frame has been constructed. This idealisation of the sequence of construction, although a simplification of the construction process actually used, can be justified if we assume that other items of work lag by about three or four storey behind the final stage of construction at any instant.

The incidence of incremental loads for a three-storeyed single bay frame simulating the sequence of construction stipulated in this study has been shown in Fig. 1.

When concrete is poured at second floor level after some interval, it is assumed that the frame has attained its strength up to first floor level. Hence the total loads applied at first floor level are dead load due to the self weight of the beam and slab of the first floor level (D_1), that of second floor level (D_2) carried to first floor level through props and the self weight of shutterings between first and second floor (S_2). Similarly when concrete has been laid at the third floor level, the shuttering has been removed from beneath the second floor and the concrete has attained its full strength up to second floor level.



'Fig.1 Pattern of analysis for simulation of construction sequence.

Removal of shuttering calls for application of an upward load (D_2+ S_2) at first floor level. The load at the second floor level at this stage is D_3+D_2+S_3. Algebraic summation of the stresses obtained from the analysis of the two-storeyed frame to those of single storeyed frame gives the net stresses developed up to the second stage of construction. It may be noted that members in lower storeys attain higher elasticities. This sequence of application of load is followed until the final stage of analysis when shuttering from below the roof has been removed. The algebraic summation of the stresses of all these stages of analysis gives the final stresses due to the self weight of structural members only.

The frame has been analysed by stiffness matrix method. In case of flexible foundation, stiffness matrix of the structure-sub-structure-soil may be derived based on the Winkler's foundation model.

RESULTS

It has been found that incremental loading concept due to the sequence of construction modifies the member forces considerably when compared to one step analysis as being followed in common practice. Some of the major observations for the two dimensional 11-storeyed frame 7 o n rigid base are as follows:

(i) In case of beam members, effect of sequence of construction is more towards the upper storeys and is maximum at one or two storeys below roof level (Table I).

(ii) From table I it can be observed that there is increase in negative moment at joint B (Fig.2) but decrease in joint moment at joint C in bay BC when the sequence of construction has been incorporated in the analysis. But, the reduction percentage at joint C in bay BC is less compared to the reduction in end moments in bays AB and CD. The central corridor bay is quite flexible as compared to the two adjoining end bays having beams. It, therefore, proves that depending on the large variation of relative stiffness in two adjacent bays, there is a reduction of end moments in the relatively stiffer bay when the effect of sequence of construction is considered. In the relatively flexible bay, there may be increase in the end moment as at joint B or if not an increase, there will be comparatively less reduction of end moments, as at

joint C of bay BC. The larger reduction of end moments at joints A and D as compared to B and C in bays AB and CD can be explained from the above argument if it is assumed that joint A and D are the common joints of two adjoining bays having (non-existent) infinitely flexible bays alongside joint A and D.

(iii) Depending on the changes in the end moments, midspan bending moments also change correspondingly as can be observed from Table I.

(iv) Referring to Fig.2, it is observed that some kink formation appears at the column joint due to incremental incidence of self weight of the members and thereby introducing locked-in deformation at the joints. Deformation diagram of joint A at first floor level upto the second stage of analysis, that is, upto the stage when all members upto the second floor level have attained full strength and load from third floor due to the self weight of green concrete and shuttering is imposed on second floor is shown in Fig. 3.

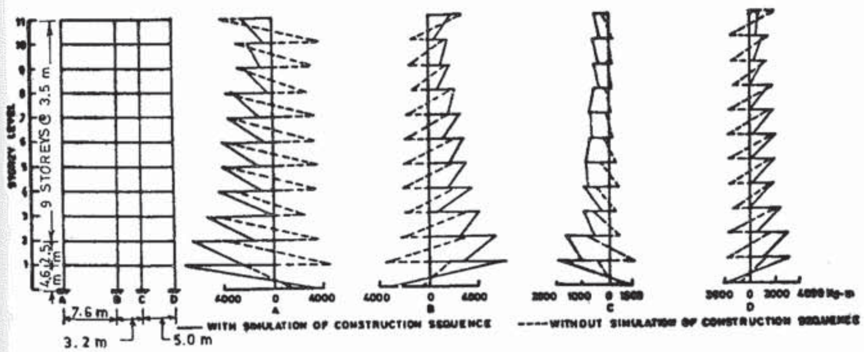


Fig. 2 Column moment diagram (self weight of members only)

(v) Due to simulation of construction sequence, design bending moments at the bottom ends of columns at any storey is decreased and those at top end is increased. However, at the top few storeys, even moments at top ends are also decreased(Fig.2).

(vi) Simulation of construction sequence changes the direct thrust in all columns, although marginally.

(vii) The effect of deformable soil underneath the foundation was studied for the 11-storeyed plane frame with two different values of soil stiffness (k_y) as 167 kg/cm^3 and 30 kg/cm^3. The higher value of ky corresponds to a fairly nondeformable foundation. The results of the analysis brought out that the effect of sequence is broadly the same irrespective of the fact that the frame is founded on a flexible or rigid base.

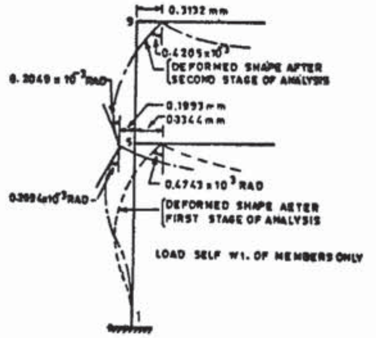


Fig. 3 Deformation diagram at node 5 (upto second stage only)

The forces obtained for the analysis with flexible base (k_y=167 kg/cm^3) are not very much different from those of rigid base case. However, when k_y=30 kg/cm^3, the values are quite different both for one step and step by step analysis specially in the lower storeys which are nearer to the flexible base (Table II).

Table III shows the comparison of bending moment in the three bays at different storey levels for flexibily supported frame (k_y=30 kg/cm^3) with sequence of construction vis-a-vis conventional one step analysis on rigid foundation. The changes in the moment due to the foundation effect and sequence of construction may be modified by about 30 percent at critical section which is one storey lower than the roof.

(viii) The effect of sequence of construction has also been studied for the same 11-storeyed frame as a three dimensional frame having four bays in the longitudinal direction at a spacing of 3.75 m c/c. In this case also, the effect of simulation of sequence of construction has been found to be of same nature. Negative bending moments at the ends of the beams in the exterior bays decrease more and more towards upper storeys and reach minimum at one storey below roof level except that at two critical sections, at 2nd and 3rd storey levels, these increase (Table IV). This was not observed in 2-D case, where all along there was decrease. Also, the percentage reduction in the negative design moments in exterior bays is less in case of 3-D frame as compared to 2-D frame.

CONCLUSIONS

It is observed that simulation of sequence of construction in the analysis of building frames leads to considerable variation in the design moments obtained by conventional one step analysis of frames with rigid base. Flexibility of the soil underneath the frame also plays an important roles in modifying the member forces. It is therefore necessary that for accurate evaluation of forces in the members, the building frames should be analysed simulating the sequence of construction and considering the flexible foundation effect. Realistic assessment of the modulus of subgrade reaction

is quite essential. Apart from the above, other time dependent phenomena like change in stiffness of members due to different ageing of members, creep and shrinkage not covered in this paper change substantially the stress configuration in multistoreyed frame. Although exact simulation of the construction sequence may be difficult, idealization on the basis of simplified model is always possible. With the use of high speed computer, the approach suggested in this paper should be adopted in the analysis of building frames.

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Table I Comparison of bending moments for self weight of members-ratio of bending moments from sequentialand one step analysis

Storey level	Beam in bay AB left end	Beam in bay AB mid-span	Beam in bay AB right end	Beam in bay BC left end	Beam in bay BC mid-span	Beam in bay BC right end	Beam in bay CD left end	Beam in bay CD mid-span	Beam in bay CD right end
1	0.671	1.483	0.702	1.088	0.925	0.987	0.784	1.388	0.725
2	0.709	1.441	0.748	1.090	0.935	0.980	0.842	1.366	0.726
3	0.742	1.319	0.788	1.080	0.950	0.975	0.905	1.263	0.777
4	0.515	1.519	0.550	1.158	0.884	0.961	0.692	1.478	0.589
5	0.461	1.517	0.483	1.210	0.877	0.938	0.635	1.579	0.538
6	0.495	1.510	0.566	1.223	0.899	0.937	0.765	1.488	0.550
7	0.381	1.590	0.493	1.292	0.866	0.906	0.730	1.577	0.440
8	0.421	1.440	0.613	1.316	0.882	0.890	0.917	1.448	0.452
9	0.237	1.471	0.495	1.400	0.848	0.849	0.851	1.240	0.271
10	0.205	1.545	0.565	1.540	0.829	0.814	0.920	1.330	0.169
11	0.581	1.134	1.014	1.325	0.916	0.814	0.149	1.188	0.368

Table II Comparison of end moments of beam in bay AB for self weight of member k_y= 30 kg/cm^3

Storey level	Bending moment considering soil interaction (kg-m)				Ratio			
	without sequence		with sequence		without sequence		with sequence	
	end A	end B	end A	end B	end A	end B	end A	end B
1	7742	-5345	5494	-3114	1.107	0.833	1.172	0.693
2	8362	-5768	6119	-4162	1.095	0.896	1.129	0.862
3	7949	-5152	5985	-4068	1.081	0.893	1.094	0.885
4	7267	-4696	3852	-2513	1.067	0.909	1.094	0.881
5	7626	-4581	3584	-2171	1.061	0.910	1.094	0.888
6	7452	-4312	3689	-2482	1.055	0.915	1.079	0.927
7	7326	-4094	2790	-1997	1.049	0.920	1.054	0.939
8	6809	-3842	2846	-2471	1.044	0.926	1.046	0.969
9	6031	-3492	1440	-1840	1.040	0.932	1.076	0.982
10	6331	-3559	1018	-1984	1.038	0.933	1.022	0.995
11	3650	-2438	1418	-2453	1.036	0.941	1.008	1.001

Table III Comparison of design bending moment in beams with soil interaction k_y = 30 kg/cm^3

Storey level	Ratio of B.M. from sequential with soil interaction vs one step analysis					
	Beam in bay AB		Beam in bay BC		Beam in bay CD	
	end A	end B	end B	end C	end C	end D
1	0.9380	0.8520	1.0066	1.0188	0.8600	1.0122
2	0.9420	0.8998	1.0088	1.0092	0.9210	0.9862
3	0.9480	0.9230	1.0080	1.0055	0.9475	0.9807
4	0.8830	0.8730	1.0328	0.9986	0.9298	0.9312
5	0.8600	0.8550	1.0494	0.9917	0.9214	0.9081
6	0.8630	0.8797	1.0551	0.9841	0.9480	0.9019
7	0.8210	0.8540	1.0763	0.9747	0.9446	0.8613
8	0.8242	0.8860	1.0851	0.9648	0.9766	0.8526
9	0.7500	0.8410	1.1120	0.9530	0.9620	0.7784
10	0.6890	0.8160	1.1449	0.9393	0.9776	0.7037
11	0.7520	0.9730	1.1420	0.9279	0.9113	0.7449

Table IV Comparison of beam moments for design values of middle frame (sequential vs one step analysis)

Storey level	Ratio of beam moments (sequential vs one step analysis)					
	Beam in bay AB		Beam in bay BC		Beam in bay CD	
	end A	end B	end B	end C	end C	end D
1	0.964	0.967	0.927	0.997	0.983	0.980
2	0.994	1.003	0.939	0.993	1.010	0.995
3	0.998	1.009	0.955	0.993	1.015	0.997
4	0.966	0.979	0.909	0.989	0.997	0.979
5	0.957	0.970	0.895	0.982	0.991	0.972
6	0.961	0.980	0.902	0.975	1.000	0.972
7	0.938	0.962	0.871	0.965	0.991	0.955
8	0.945	0.977	0.867	0.952	1.004	0.956
9	0.896	0.938	0.796	0.932	0.980	0.917
10	0.834	0.884	0.763	0.905	0.928	0.847
11	0.892	0.972	0.736	0.868	0.984	0.823