Earthquake Engineering, Tenth World Conference © 1992 Balkema, Rotterdam. ISBN 90 5410 060 5

Modeling frames with shear walls: Linear or finite elements

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ABSTRACT: This study was directed to find the best alternative for modeling beams ending at shear walls as linear elements with rigid arms for use in dynamic or static matrix structural analysis for earthquake loading. Comparisons were performed with finite element analysis considering this one as the target objective. Best modeling to compute local and global forces as well as displacements was to consider 75% of half wall width for beams and 75 of half beam depth for column ends (75BC). Full half wall width is also adequate but for force estimations only. Further research using finite element inelastic analysis is recommended to study influence of plastic zones in the response.

1 INTRODUCTION

Shear walls are commonly used as an earthquake resistant system for reinforced concrete structures, alone, in combination with frames or as part of them.

With availability of computers, matrix methods for structural analysis of these combined frame-shear wall systems have become a standard in design practice. In matrix methods elements of the frame-shear wall system: beams, columns and walls, are represented as straight lines (Figure 1). However a decision has to be made as to how to include those portions of beams which end in walls, or those portions of columns which are part of the joint or beams. Since all elements are considered linear, joints are defined at their intersection. Usually these end portions are modelled as infinitely rigid but the length of this portion remains to be decided to adequately quantify its actual rigidity. A variety of suggestions for the length of this rigid arm in relation to wall width have been made, but no justifications are given.

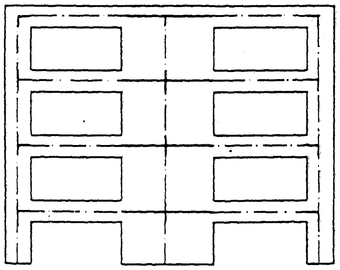

Figure 1. Modeling of frame with shear walls with linear elements for matrix structural analysis

This study focuses on different alternatives to model this end part of beam and column and determines the best alternative to reproduce an "exact" response, this latter defined as the one calculated using finite element methods.

Research was divided into three parts:

a) A local investigation of a typical joint beam-shear wall using finite elements in order to evaluate the simplest mesh which could adequately represent the behavior under lateral loads.

b) An inelastic analysis in order to evaluate stress concentration at the joint and to compare with elastic analysis.

c) Comparative analysis by matrix methods using linear elements with different alternatives of rigid end arms for beams and columns and by finite elements of frames with shear walls of 4, 8, 12 and 15 stories.

2 FINITE ELEMENT ANALYSIS

A beam-shear wall and a beam-column substructures under lateral loads were used to study stress distribution at the joint and to find a simple mesh for analysis of the whole structure in the following stage.

An 8 node quadrilateral isoparametric element of the "serendipity" family was used. Trials were made using different meshes. A fine mesh with 4 elements across beam depth and a total of 40 elements in the beam and 108 elements in the wall portion (Figure 2). A coarser mesh was found to be adequate using only 2 elements in depth and a total of 16 per beam and 24 in the wall portion. Based on a particular computer program written by Scaletti (1988) routines were added to plot meshes and stress variations.

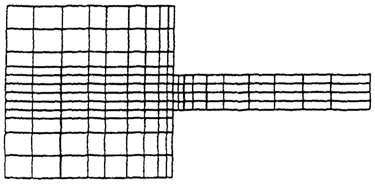

Figure 2. Beam-wall joint fine mesh for finite elements elastic and inelastic analysis

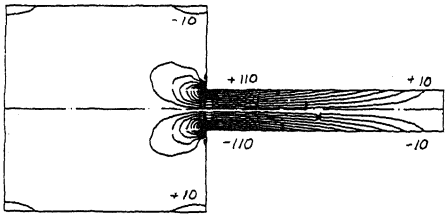

Figure 3. Stress concentration at beam wall joint from finite element analysis

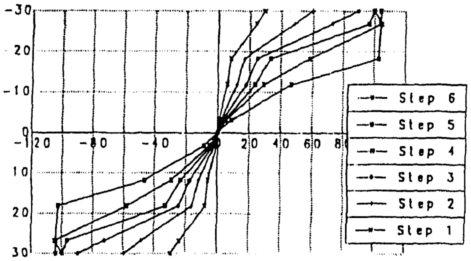

Figure 4. Inelastic stress distribution at beam wall joint

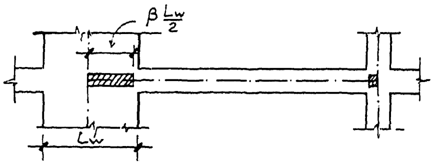

Figure 5. Beam Element

The assemblies were subjected to a state equivalent to that produced by a lateral forces system acting on the whole frame. Analysis at this stage was linear elastic.

Relevant findings were: high stress concentration at the beam wall and beam column joint (Figure 3); nonlinear stress variation; low normal stresses at the wall due to sudden increase in cross sectional area.

3 INELASTIC ANALYSIS OF JOINT ASSEMBLY

An inelastic analysis was performed using the same fine mesh mentioned above with Von Mises yield criteria to evaluate stress concentration and plastification at the joint and to compare with elastic analysis. NONSAP (Wilson et al. 1974) was used to carry this on. Yield stress was defined as that of concrete 0.45 f'_c which is equivalent to $f_y = 10$ N/mm^2 for normal concrete of $f'_c = 21$ N/mm^2. An implicit assumption is made that tension stresses in concrete are resisted by reinforcing bars and therefore same yield capacity is considered for both tension and compression stresses. This is due to a limitation by yield criteria which is most appropriate por metal structures.

Load deflection of the joint appears linear up to the 4th loading stage in which overall nonlinear behavior becomes visible. About 40% of beam depth becomes plastified for a load level corresponding to the seismic code of Peru. At beam cross sections close to the wall stress distribution is never linear (Figure 4). As load increases distribution becomes elasto-plastic.

It is clear that beam sections ending in shear walls are overstressed and undergo plastic behavior even for reduced (because ductility factors) code load levels. This indicates that elastic analysis may not be adequately representing actual force and moment distribution. (Figure 4)

4 LINEAR VS. FINITE ELEMENTS

Four typical reinforced concrete frames with a center shear wall 4, 8, 12 and 15 stories high were analyzed. These were modelled with linear elements with rigid end arms of different length and also using finite elements.

Rigid arm length is measured from the joint defined by the intersection of wall axis and beam axis. This length is taken as half wall or column depth multiplied by a factor β (Figure 5). Four alternatives for the end rigid arm were investigated:

- Rigid arms only in beams of length equal to half wall width (denoted by 100B)
- Same as case before but arm length equal to 75% of half wall width (denoted by 75B)
- Rigid arms in both beams and columns of length equal to half wall width and half beam depth (100BC)
- Same as before but length equal to 75% of half wall width and 75% of half beam depth (75BC)

Finite element modeling for each typical floor is shown in Figure 6. Mesh for all frames was generated automatically through a routine written for this work.

Loads applied were those of the Peruvian seismic code as applied to a whole building. A pseudo three dimensional analysis was performed to determined the forces allocated to each frame.

5 RESULTS

5.1 Displacements

In all four frames displacements estimated using 75BC

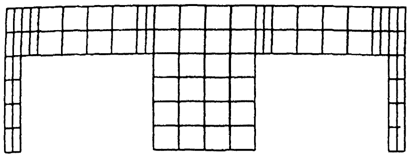

Figure 6. Typical mesh for each story

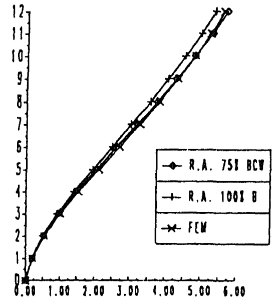

Figure 7 Displacements for 12 story frame. FEM solution and 75BC and 100B alternatives

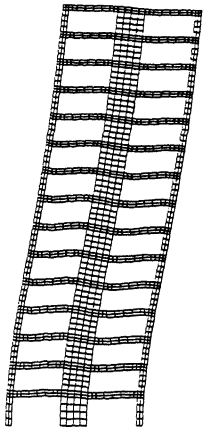

Figure 8. 15 story frame. Lateral loads deformed mesh

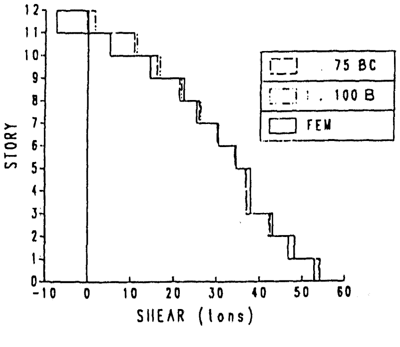

Figure 9. Shear at wall of 12 story frame. FEM solution versus 75BC and 100B

and 100B alternatives gave the closest results to FEM solution. In Figure 7 floor displacements for the 12 story frame are shown for these three cases. The best approximation is obtained when 75BC is used.
In Figure 8 the deformed shape of the FEM model for the 15 story frame is shown. Top four stories show a curvature change resulting in an upper portion more rigid as compared with the 75BC or 100B alternatives using linear elements. This tendency which appeared only for the 15 story frame needs to be investigated using a finer mesh and a taller structure.

5.2 *Global Forces*

All four alternatives give good approximation to FEM solution up to the 8th floor. In the upper stories discrepancies increase considerable, specially at the top floor where FEM predicts a change in sign for the shear force. However absolute values are relatively small. In Figure 9 shear force distribution for the wall of the 12 story frame can be observed for the 75BC and 100B alternatives as compared to the FEM solution.

5.3 *Local forces*

Local forces, such as bending moments, shear and axial forces were also computed for all frames. Figure 10 shows stress distribution at the wall of the four story frame. Stress concentration is clear at the beam wall joint as expected.

In general linear elements underestimate local forces in the lower stories and overestimate them in the upper stories.

As an illustration Table 1 shows moments in beams for 15 story frame
As compared with finite element analysis, linear elements with a 100% of rigid arm length for the beam only (100B) give closest results. This alternative has the advantage of being already implemented in many available computer programs.

6 CONCLUSIONS

Best modeling to compute local and global forces as well as displacements is to consider 75% of half wall width for beams and 75 of half beam depth for column ends (75BC). 100B is also adequate but for force estimation only.

Further research using finite element inelastic analysis is recommended to study influence of plastic zones in the response.

It would be convenient to extend the study of beam wall connection using three dimensional finite elements to account for transverse frames

A study of frame behavior using finer meshes could be convenient to investigate discrepancies with matrix methods in frames taller than 12 stories.

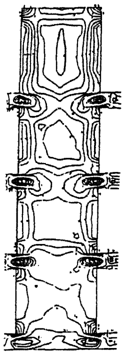

Figure 10. Qualitative stress distribution in 4 story shear wall from FEM analysis. Severe stress concentrations are observed at beam wall joint.

Table 1. Bending moments in beams of 15 story frame

Floor	Model	Shear	Moment i	Moment j
1	FEM	-5.584	-14.92	-15.49
	100B	-5.338	-14.60	-15.55
	75BC	-4.998	-14.60	-13.64
2	FEM	-8.212	-21.85	-22.86
	100B	-8.019	-21.89	-23.42
	75BC	-7.403	-21.60	-20.23
5	FEM	-9.431	-24.91	-25.94
	100B	-9.463	-25.92	-27.55
	75BC	-8.879	-25.94	-24.23
8	FEM	-8.508	-22.57	-23.57
	100B	-9.474	-25.83	-27.69
	75BC	-9.136	-26.57	-25.04
12	FEM	-4.178	-11.12	-11.57
	100B	-6.045	-16.60	-17.55
	75BC	-6.032	-17.62	-16.46
15	FEM	-2.188	-5.29	-6.29
	100B	-4.026	-10.50	-12.25
	75BC	-4.398	-12.36	-12.48

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