MODELING THE STIFFNESS CONTRIBUTION OF INFILL PANELS TO FRAMED STRUCTURES BY A CONSTRAINT APPROACH

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SUMMARY

A means to model the stiffness contribution of infill panels to framed structures, based upon a simplifying constraint assumption, is presented. The accuracy of the method, the development of "infill elements" based upon the method, and the generality of the method are discussed.

INTRODUCTION

Infilled frame structural systems, wherein conventional frames of reinforced concrete or steel are filled, in their plane, with construction usually of masonry, have resisted analytical modeling, although they have been studied experimentally for many years [1,3,4]. Yet, or perhaps because of this, buildings utilizing frame-infill systems have consistently performed poorly in past earthquakes. Frame-infill systems continue to be used throughout the world, however, as they provide an economic and direct means to enclose and partition space that suits many local building traditions.

THE CONSTRAINT APPROACH

Frame-infill systems have been modeled by either an "equivalent strut" approach or by refined finite element discretization [4,5,6,8,9]. The former method is intuitively and computationally attractive, yet theoretically weak and relatively unsuccessful while the latter approach is computationally prohibitive although apparently effective. This paper presents a modeling approach that falls between these two extremes that may be thought to be an extension of the idealization suggested by Newmark [7] where the infill is assumed to act as if it is constrained by a rigid linkage.

Constraint Assumption. Here it is assumed that the frame constrains the form, but not the degree, of the deformation of the infill. This assumption follows naturally from the consideration of a system that has a very stiff frame and relatively soft infill. Clearly, if the infill is sufficiently soft, relative to the frame, then the posed assumption will be valid. The assumption suggests a general approach of modeling the structural behavior of other "secondary" structural elements (eg. stairways, floor slabs, windows, etc.) where it may be reasonably assumed that the primary structural system acts to constrain the form of deformation of the secondary structural system. Three questions remain, however; (1) How may this assumption be implemented practically? (2) What form of constraint is to be assumed? and (3) Is typical infill construction 'sufficiently soft' to be accurately modeled this way?

Implementation. This kinematic assumption may be realized by constraining a suitable mesh of plane stress elements to the nodal degrees of freedom of

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of the surrounding frame composed of conventional beam elements. For rectangular geometry (Fig. 1) the system is modeled by separate assemblages of finite elements for the frame and infill. The separate stiffnesses are formed and the stiffness of the infill alone is reduced, by condensation, to the boundary degrees of freedom. A constraint relation is assumed between the 12 frame degrees of freedom and the infill boundary degrees of freedom thereby allowing a congruent transformation of the separate systems to a composite approximate frame-infill system with only 12 degrees of freedom. It is seen that the infill contribution is distinct and is simply added (in a direct stiffness assembly sense) to the frame stiffness. Frame-infill systems of greater complexity may then be modeled in a similar manner.

Constraints. Although a wide range of constraints may be considered [1] two types of constraints are of particular interest as they offer conformation of the infill and frame deformations. In the first constraint the boundary of the infill is constrained to deform transversely to the flexural beam shape function, the cubic hermitian polynomial shape function, and longitudinally to the truss shape function, the linear shape function, as these two shape functions define the deformation of the general beam element. The second constraint utilizes only the transverse constraint. The first constraint may, then, be thought to approximate the behavior of "stiff" infill panels monolithic with the frame while the second constraint will result in a "soft" infill panel that may better approximate the behavior of typical masonry panels.

Infill Elements. In effect, the approach is an approximate finite element substructuring technique that leads naturally to the development of infill elements that may simply be "plugged" into conventional frame analysis programs. The use of such elements will not substantially increase the size of the system of equations that would be solved for the frame alone. The approach allows the development of a large variety of infill elements including elements to model completely as well as partially infilled frames, unusual infill geometry, possibly with openings, as well as unusual infill material properties or constraint conditions.

Four homogeneous linear elastic infill elements corresponding to completely and partially infilled frames with either "stiff" or "soft" constraint assumptions assumed have been studied. The complete and partial "stiff" infill elements may be reasonably compared to a conventional finite element idealization (the "exact" scheme of Fig. 1). Such a comparison reveals that (1) the assumption is indeed more accurate with softer infill panels, (2)the assumption is reasonably accurate for practical infill construction, and (3) framing member forces as well as infill stress levels are captured reasonably well, albiet, in only a best-fit-mean sense (Fig. 2).

Comparison with experimental test results (Fig. 3 is one example) has proven to be encouraging also. These four infill elements were used in a detailed dynamic analysis of a relatively complex building damaged during the 1976 Guatemalan earthquake with some success (see Ref. 2, a paper presented at this conference).

Computational Efficiency. The generation of the infill elements, as suggested, represents a computationally costly task that may be justified when few infill panels or many identical infill panels are to be modeled. To avoid this computationally difficult task a nondimensional parameter study may be used to relate individual nondimensional infill stiffness terms to the aspect ratio of the infill panel by polynomial approximation [1]. Using these polynomial approximations infill stiffnesses may be computed with little effort. This was done but the approach demands further development.

CONCLUSION

It is believed that infilling frames may provide an effective means to stiffen and strengthen framed structures, eventhough experience suggests the contrary, if (1) an effective means to model the seismic response of frame-infill systems is developed and (2) frame-infill design details are sought that will improve the hysteretic behavior of these systems. Klingner and Bertero [4] have addressed this latter need and the constraint approach presented in this paper addresses the former need.

Frame-infill system response behavior is not yet well understood. The constraint approach aids only in predicting the initial elastic behavior of such systems. Additional research may most effectively be directed toward improving and predicting the inelastic response of these systems, the constraint approach may, conceivably, be adapted to these purposes as the method is theoretically consistant and yet very flexible in the types of elements that may be developed.

For the purposes of modeling the initial elastic response of frame-infill systems the constraint approximation appears to provide a degree of accuracy well within the inevitable uncertainty of the infill material stiffness, homogenaity, and continuity. It is important to note, finally, that in every case considered the infill had a primary, even dramtic, influence upon system behavior that cannot, reasonably, be ignored.

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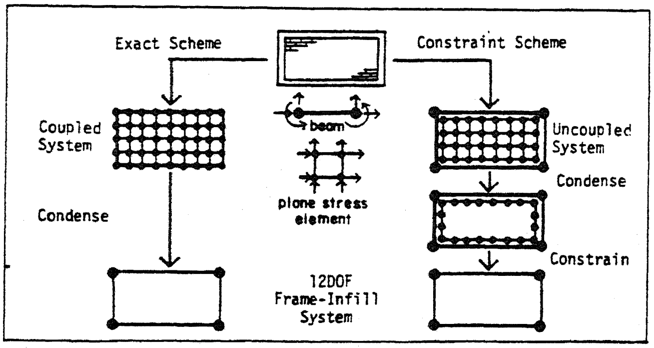

Figure 1. Comparison of the Constraint Approach to a Convential Finite Element Idealization

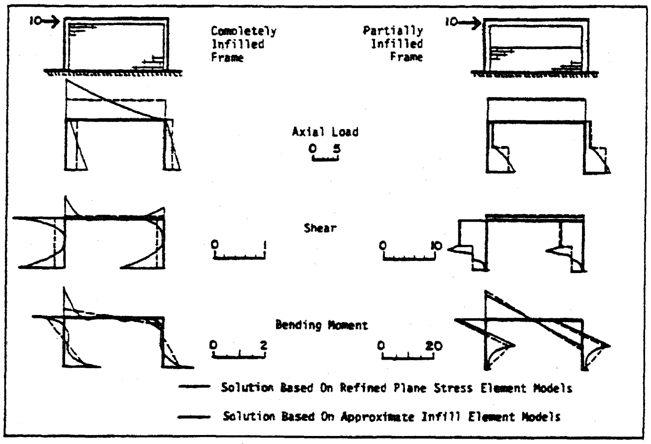

Figure 2. Accuracy of the Constraint Approach: Member Force Evaluation

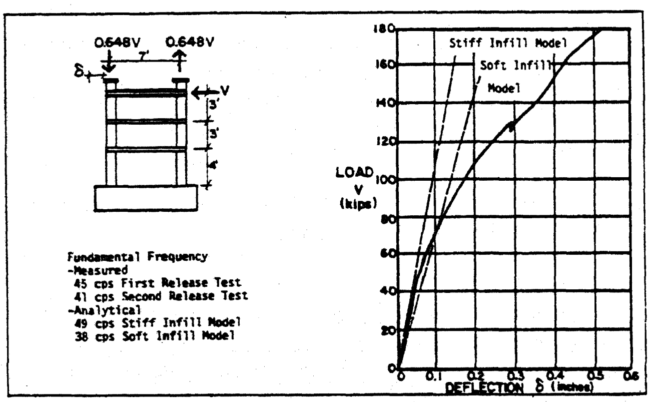

Figure 3. Accuracy of the Constraint Approach: Comparison to Vallenas' [10] Experimental Results