Constraints for frame beams in nonlinear analysis using ABAQUS

X.M. Chen, J. Duan Jin, Y.G. Li

China state construction technical center, Beijing, China

KEYWORD: Constraint, ABAQUS, Elastic-plastic, Time-history analysis
ABSTRACT: Constraints are used widely for linear structural analysis in professional software, but some ofthem may be neglected in nonlinear analysis while using general FEA software. Two kinds of constraints, include panel zone at beam end and top alignment of beam and slab, are analyzed by numerical method. Numerical example shows that results with both kinds of constraints being taken as the reference value, the model only with panel constraints would amplify the structural stiffness improperly, the model without any of these two constraints would underestimate both damage of beam ends and floor drift angle at structural bottom, and top alignment of beam and slab which is seldom considered in engineering can improve the numeral precision effectively.

INTRODUCTION

In structural analysis, to simulate stiffness accurately depends on reasonable compatibility between elements. Except the fundamental form of nodal deforming compatibility, there are some special compatible controls need be simulated by constraint, such as DOF release, rigid diaphragm, eccentricity and so on.

Take eccentricity for instance, it is used to locate frames or walls accurately. The eccentricity of wall means the shift along its normal direction, and the eccentricity of frame is the shift along its local 1 or 2 axis. In most of FEA software, usually the nodes for DOF definition are independent of eccentricity which is only one of the properties of sections. But it may be quite different in professional software for building structures. For the purpose of more accurate size of structural member and load, the pre-process of these kinds of software may transform the eccentricity into nodal coordinate translation. Applications show that these methods can exhibit preferred results for engineers.

As a kind of special eccentricity, the relative position between slab and beam may be often neglected in building structures. Conventional method in professional software is to assume the neutral axis of beam aligned with neutral plane of slab. As this would underestimate the constraint on beam flexure supplied by slab, a factor proposed by Chinese national code(2011) is used to amplify the bending stiffness of beams for making up the loss. This Special method can ensure the beams with enough safety-margin. Although relative options are available for users in new versions of some software, but it still cannot take place of the stiffness factor till now.

Stiffness factor is used to amplify beam's bending stiffness directly, so it is not suitable to be extended to nonlinear analysis under rare expected earthquake. To simulate the interactions accurately between beam and slab, eccentricity should not being neglected any longer.

Except the constraint for eccentricity about beam and slab, another special kind of connection between beam and wall is also being emphasized by engineers. Constraint is often used to overcome the theoretical defect for in-plane rotational DOF definition of shell firstly, and secondly, sometimes it is inappropriate to neglect the action of beam's section height on wall. Panel elements are preferred by professional software, such as PKPM(2009), GSCAD (2010) and YJK(2012), to enhance the stiffness of conjunctions. Engineering applications show that without this constraint, the bending moment at beam end would be underestimated more or less.

For any FEA software, the solution of structural nonlinear analysis under seismic wave depends on the reasonability of mechanical model. Take ABAQUS as example, both eccentricity and conjunction mentioned above can be simulated with MPC method or connector elements. Although these constraints can improve the precision, some engineers may be puzzled by the phenomenon of

overconstraint in the process of modeling, thus, these complex constraints may often be neglected for practicability.

By numerical method, the influence of different conjunctional models on internal force and damage of structural members is analyzed, the effects on floor drift angle which is the most important structural global index is also presented. The results can be taken as references according to different requirements.

Description of structural model

Four different mechanical models are used for simulating the conjunction between beam and slab/wall, they are as follows:

Model A(Direct): Without panel constraint at conjunction of beam and wall, without top alignment of beam and slab;

Model B(Panel): Only with panel constraint at the conjunction of beam and wall;

Model C(BeamH): Only with top alignment of beam and slab;

Model D(Panel_BeamH): Both B and C.

For the constraint at beam end connected to shear wall, connector element named UNIVERSAL(2009) is available in ABAQUS. By local coordinate system, the nodal rotations of those nodes in beam section would be fixed about one local direction and free about two others as shown in Fig.1.

Fig.1 Connector element of UNIVERSAL

Although both relative translational DOFs and rotational DOFs would be restrained in professional software for structural design, the connector element shown in Fig.1, which only restrain the rotational DOF of point a and b about local 1 axis, still can present precise bending moment as the former.

The structural shown in Fig.2 is taken for numerical example, in which the schedules of alignment between beam and slab are presented too.

Structure in Fig.2 would be loaded with gravity firstly, and then seismic wave would be applied on the embedded points at the base. Both material and geometric nonlinearity would be considered in these two procedures.
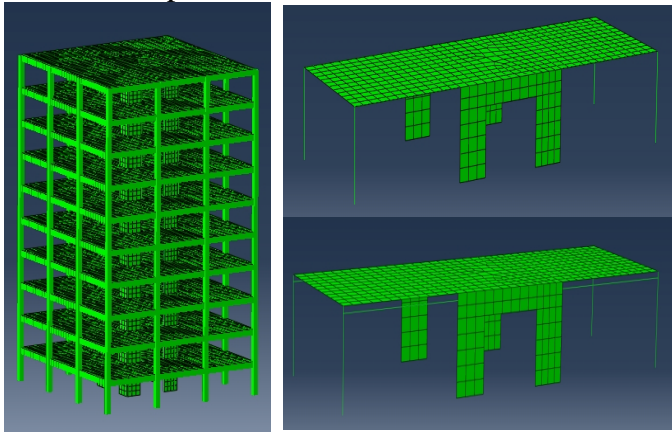

Fig.2 Model of numerical example

COMPARISON OF MEMBERS

As the bending of beam would be restrained by constraint between beam end and wall corner, the compression damage of beam end would become more serious under seismic, and the force at the corner of shear wall would also be different with that connected only by unique node; on the other hand, top alignment of beam and slab would decrease the deflection of beam with part of strain energy being transmitted into slab. The results of beam and shear wall of first floor shown in Fig.2 are used for comparison.

The bending moments of beam under gravity are shown in Fig.3：
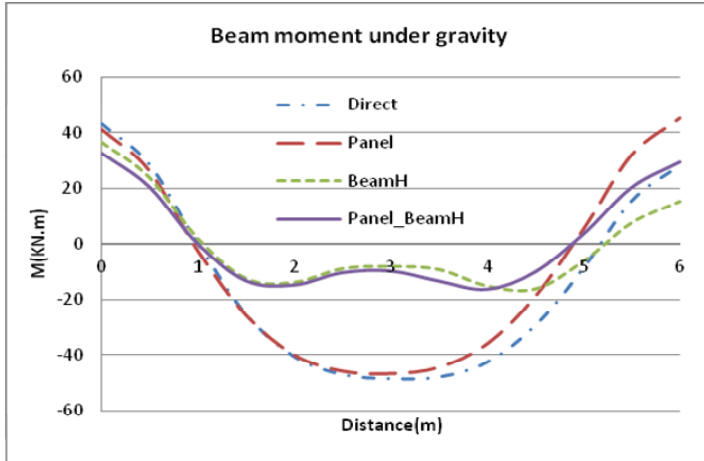
Fig.3 Bending moments of beam under gravity

For these four kinds of model, difference of curves is significant. In model B, only with panel constraint, the bending moment at right end of beam is much greater than the model Direct; while only with top alignment of beam and slab, bending moments at mid-span and right end are much smaller than model Direct; in model D, with both kinds of constraint, the bending moment at right end is similar with model A, and it is similar with mode C at mid-span. It can be seen that neither model B nor model C can exhibit satisfied performance for both mid-span and right end.
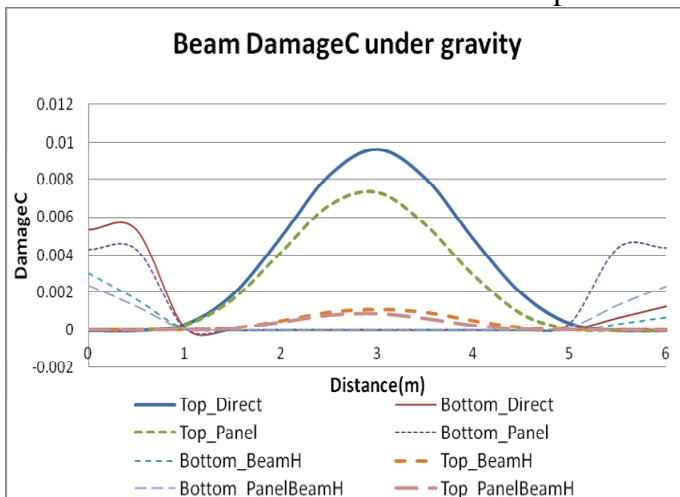

Fig.4 Compression damage of concrete under gravity

The compression damages of concrete under gravity centralized at the top of mid-span and bottom of ends as shown in Fig.4. If take model D as the reference criteria, the precision of compression damage for model B still cannot be compared with model C.
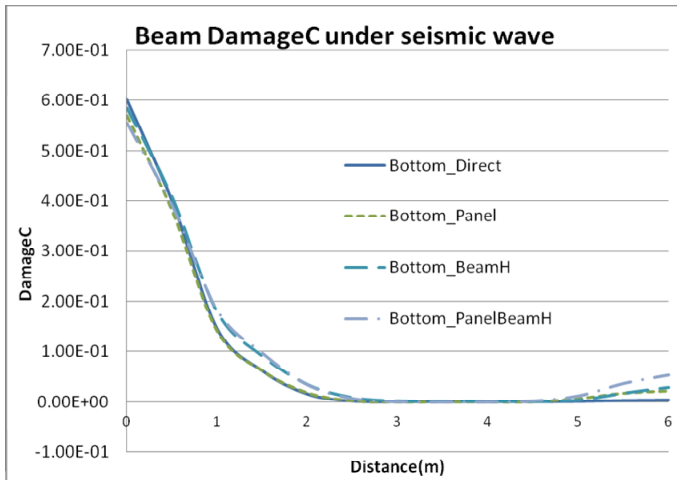
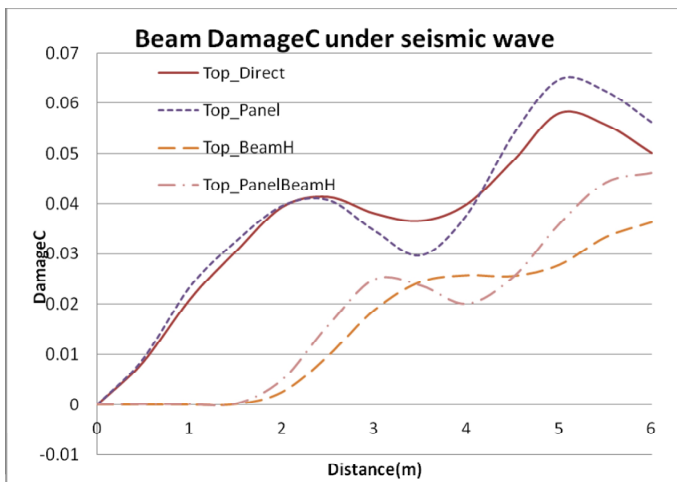Fig.5 Compression damage at beam's bottom under dynamic

Fig.6 Compression damage at beam's top under dynamic

The compression damages of bottom under seismic wave centralized at left end with small tolerance for all models as shown in Fig.5, but results of beam top are quite different as shown in Fig.6.
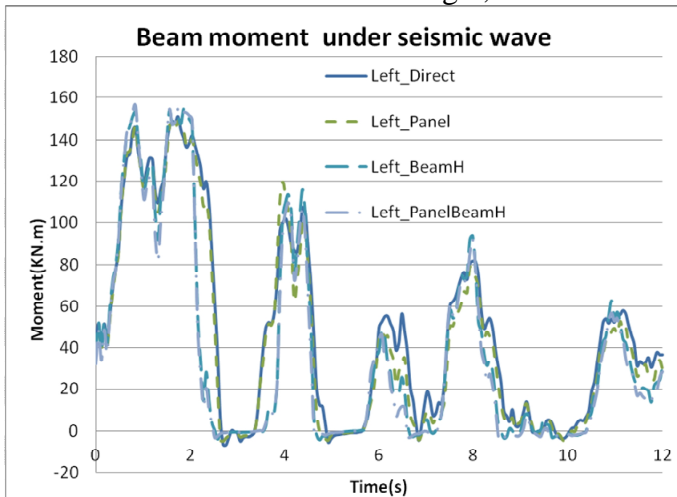

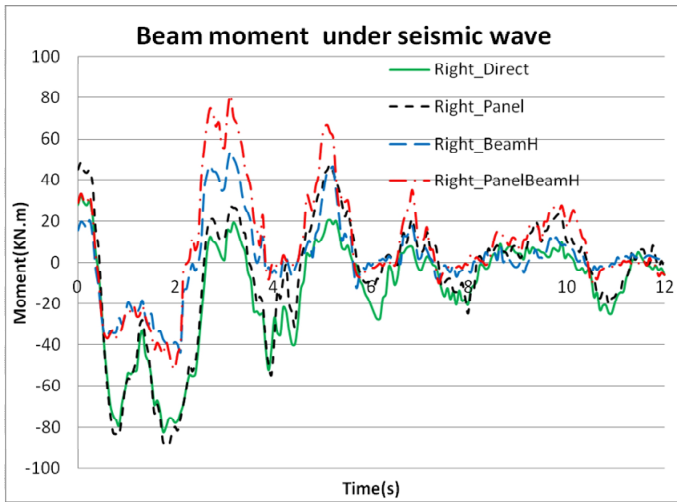Fig.7 Time-history of bending moment at left end

Fig.8 Time-history of bending moment at right end

The time-histories of bending moment at left end are quite similar for all models as shown in Fig.7, but the comparison in Fig.8 exhibit significant difference at right end, and it seemed that the results of model A and B are not unreliable any more.
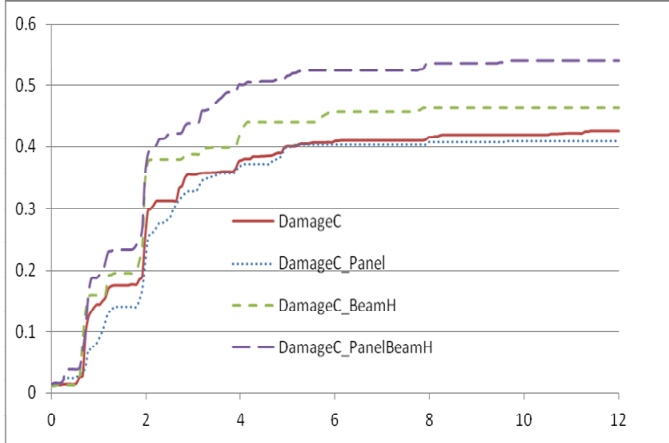

Fig.9 Compression damage at wall top-left corner

As shown in Fig.9, model D presented the most serious compression damage at wall top-left corner, and then mode C. Compared with model D, mode A and model B undervalued the results about 20%.
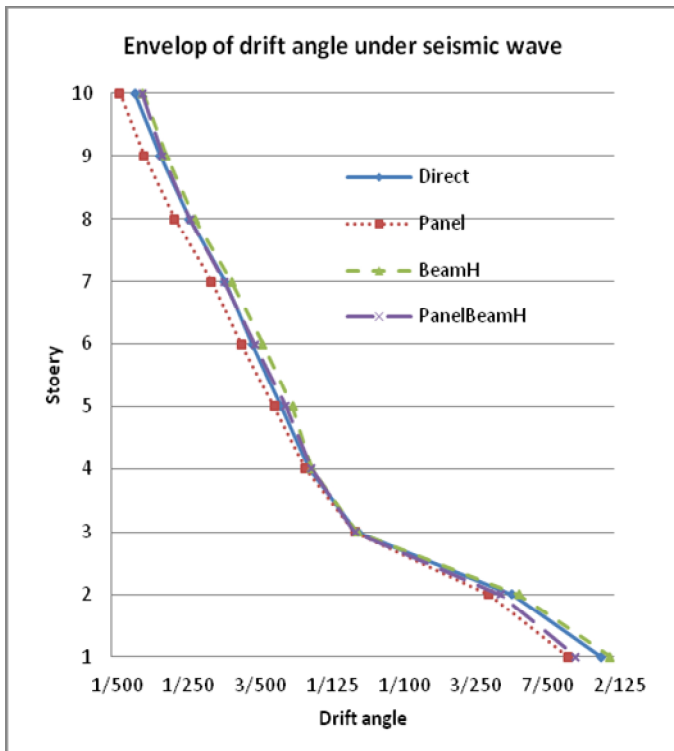
STRUCTURAL GLOBAL INDEX

Fig.10 Envelope of floor drift angle under seismic wave

Compared with those direct correlated members, the influence on whole structure induced by local constraints is not so significant, but there are still about 10% deviation for bottom values and 30% deviation for top values respectively. And the model of panel constraint, which is used most widely, may underestimate risk of collapse, especially for the top part of structure.
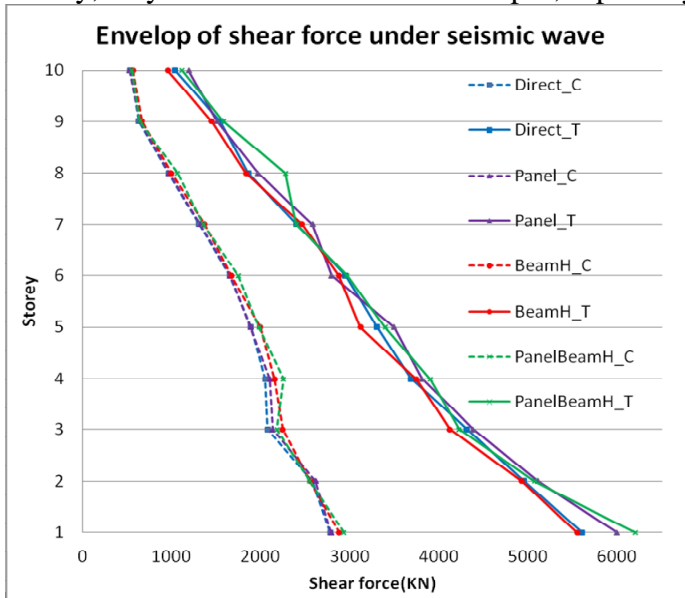

Fig.11 Shear force envelope of columns and floor

The envelope of shear force shown in Fig.11 is taken as the basis of structural optimization. It can be seen that panel constraint at beam end will enhance the structural global stiffness more than top alignment of beam and slab.

SUMMARY

For precise stiffness, extra constrains may need to be applied as supplement of nodal compatible for simulating eccentricity, DOF release, rigid diaphragm or something else. Panel constraint at beam end is researched together with top alignment of beam and slab by numerical method. Numerical results show that although panel constraint is used widely by engineers, it sometimes may underestimate the damage of both members and the whole structure more or less. If these two kinds of constrains cannot be used together, it should be emphasized that model A will underestimate both damage of beam ends and floor drift angle at structural bottom, the panel constraint in model B maybe amplify the structural stiffness improperly, and top alignment of beam and slab in model C can improve the numeral precision effectively.

REFERENCE

− China architecture & building press(2011). Code for design of concrete structures., Beijing, China. (In Chinese).
− PKPM Inc(2009). PMSAP User Manual(In Chinese).
− GSCAD building software Inc(2010). GSSAP User Manual(In Chinese).
− YJK Inc(2012). YJK User Manual, V1.7(In Chinese).
− ABAQUS Inc(2006). ABAQUS User Manual, V6. 5. 5.