Modeling of coupling beams in shear walls

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Introduction

In PERFORM, coupling beams for shear walls can be modeled using Frame elements or Wall elements. This note considers some of the modeling issues and suggests methods for modeling coupling beams.

Deep Coupling Panels

Deep coupling panels are most likely to be controlled by shear, rather than bending. Because of this they can be the simplest to model. Figure 1 shows models some possible models.

The following are some points to consider:

1. In Figure 1(a) the floor slab is at the top of the panel, and the panel can be modeled using a single wall element. In Figures 1(b) and 1(c) the floor slab is within the depth of the panel, and there is a line of nodes at the floor level. The panel can be modeled using two wall elements, as in Figure 1(b). Alternatively it might be possible to use only a single element, as in Figure 1(c). This last model is not recommended as it may increase the band width of the structure stiffness matrix, and hence may increase the analysis time.

2. With the models in Figure 1(a) and 1(c), the shear strain in the wall element can be used as the demand-capacity measure. For the model in Figure 1(b) it may be necessary to use a Shear Strain Gage element that covers both wall elements.

3. The wall elements also have axial and bending stiffnesses, in the vertical and horizontal directions. For vertical axial and bending effects it should be reasonable to use an elastic cross section. For horizontal axial and bending effects the cross section is automatically elastic (assuming that the wall element is oriented in the usual way). One concern may be that the axial and bending effects may artificially stiffen the piers, particularly if a pier is cracked in tension. To be conservative, it might be wise to make the axial and bending stiffnesses small (possibly very small) by specifying small elastic moduli, so that there is no stiffening effect. An alternative is to use a General Wall (rather than Shear Wall) element, and to specify fiber sections both vertically and horizontally, to allow cracking in tension. Still another option is to use an Infill Panel element, which has only shear stiffness and no axial or bending stiffnesses.

Figure 1: Deep Coupling Panels
Slender Coupling Beams

Slender coupling beams may be controlled by bending or shear. These are also relatively simple to model, using Frame elements. Figure 2 shows some possible models.

1. The coupling beam element can be modeled with moment and/or shear hinges in the usual way, depending on whether bending or shear governs. If the beam acts compositely with the floor slab, this should be taken into account when calculating the beam stiffness and strength.
2. The beam element must be connected to the piers by "imbedded" beam elements. If this is not done, the coupling beam will be effectively pin-connected to the wall.
3. If a pier is modeled using a single element across its width, as in Figure 2(b), the imbedded beam element will extend across the width of the pier. If the pier is modeled using several elements across the width, the imbedded beam can extend over one or several elements. In Figure 2(c) the imbedded beam extends over the full width of the pier.
4. Figure 2(d) shows one model for the imbedded beams. The beams are stiff in bending, to provide a stiff connection between the pier and the coupling beam. The imbedded beam should have only a small axial stiffness, to avoid adding stiffness to the wall elements.
5. Figure 2(e) shows an alternative model for an imbedded beams. In an actual wall, there may be substantial local deformation where the beam connects to the pier. In Figure 2(e), the rotational stiffness of the elastic connection component can be chosen to provide an appropriate amount of fixity (if it is known). It may be noted that the degree of fixity may have an effect on the elastic stiffness of the structure, but after the coupling beam yields, in bending or shear, the amount of end fixity is likely to have little effect.

Figure 2: Slender Coupling Beam

Moderately Deep Coupling Beams, Floor Slab at Top of Beam

Moderately deep coupling beams are the most complex to model. Figure 3 shows possible models for the case where the floor level is at the top of the beam.
The following are some points to consider.

1. In a deep coupling panel, bending deformations are small, and most of the deformation is associated with shear, even in the elastic range. As a coupling beam gets less deep, bending deformations can be more important, and may need to be modeled.

2. Coupling beams can be modeled using wall elements, as in Figure 3(b), but this raises a number of issues. If there are substantial bending deformations, it may be necessary to use General Wall elements, with fiber sections both horizontally and vertically (an alternative is to use Shear Wall elements, and to rotate them so that the fibers are horizontal). As indicated in Figure 3, if there is a floor slab the neutral axis of the beam will be close to the slab level (exactly at that level if a rigid diaphragm is assumed). This may over-estimate the bending stiffness. Perhaps more importantly, when a reinforced concrete fiber section cracks, the beam must extend axially, and if the extension is restrained, then so is the cracking. This can have a substantial effect on both the stiffness and strength in bending. If you use wall elements to model coupling beams that have substantial bending, you should check the behavior by analyzing small structure with one or two beams (making sure to have similar restraints as in the full structure).

3. Moderately deep coupling beams can be modeled using Frame elements, as shown in Figure 3(c). In this case, instead of using horizontal imbedded beams to connect the coupling beam to the piers, it may be better to use vertical beams, as shown. These beams should be stiff enough in bending to provide a stiff connection to the piers. They should have negligible axial stiffness to avoid stiffening the piers in bending. In Figure 3(c), the shear forces and any axial forces from the coupling beam are transferred to the piers through the upper nodes, at the coupling beam level. Bending in the coupling beam is transferred to the piers by the additional vertical beams (as a tension-compression couple).

4. If you use Frame elements you must calculate the bending and shear stiffnesses and strengths, and specify them directly. This may require more work to set up the analysis mode, but it has the advantage that it gives you closer control over the coupling beam properties. In particular, you can use judgment to assess the effect of the floor slab. If you use Wall elements, you are relying more on the analysis to calculate the properties. Also, if you use Frame elements with moment hinges, there is no axial growth when the hinges yield. This does not mean that axial growth is not present or important, but it allows you to account for it by engineering judgment rather than through the analysis process.
Figure 4 shows possible models for the case where the floor level is within the depth of the coupling beam. The points to consider are similar to those in the preceding section.

**Figure 4. Moderately Deep Coupling Beam, Floor Level Within Beam Depth**

(a) Case With Floor Slab Near Middle of Beam

If a rigid diaphragm is assumed, the neutral axis for the beam cross section is at the slab level (there is zero strain at the diaphragm level.) If the floor slab is modeled explicitly, it acts compositely with the wall elements. The neutral axis is likely to be close to the slab level. In both cases, axial extension of the beam wants to occur as it cracks, but this axial extension is restrained.

(b) Model Using Wall Elements

Elastic beams. 
$E/I/L = \text{about 50 times larger than } E/I/L \text{ for the coupling beam.}$

$EA = \text{small.}$

Shear force in beam is transferred to wall through this node.

(c) Model Using Frame Elements

**Conclusion**

A coupling beam of any depth can be modeled using either Frame or Wall elements. Although it can require more initial effort to use Frame elements, they have the advantage that they give you better control over the properties of the analysis model. Wall elements can be simpler to use, but their behavior is less certain, and possibly inaccurate.