# CHAPTER 3 VALIDATION OF FINITE ELEMENT MODELING PROCEDURE

## 3.1 INTRODUCTION

As part of this study, a finite element model was developed to analyze large, steel, moment end-plate connections that are becoming more and more attractive as earthquake resistant moment connections, but do not have adequate design methods. The validation procedure for the model is presented in the next section.

## 3.2 VALIDATION OF FINITE ELEMENT MODEL

A FORTRAN program, *R-FLANGE,* is one of a series of programs developed as part of this study to generate input files for the ANSYS finite element program. *R-Flange* is used to mesh the beam-to-column intersection and end-plate configuration for most types (flush, extended, extended-wide, stiffened, etc.) of moment end-plate connection configurations based on several user-supplied connection details. The user provides the type of end-plate, geometric parameters, material properties, size of bolts, and bolt pretensioning forces. Either hot-rolled or built-up sections can be specified. Weld access holes are not considered since it has been shown sufficiently in the literature that they are detrimental to the performance of moment end-plate connections (Meng, 1996). The end-plate is connected to the beam via a full penetration weld. Therefore, the beam and end-plate are assumed to be continuous. In other words, the finite element meshes are constrained together at the intersection.

In lieu of an exhaustive discussion of all validation tests performed, two representative cases shown in Figs. 3-1 and 3-2 are described to demonstrate the program's accuracy. The experimental values can be found in Srouji et al. (1983) and Morrison et al. (1985). The first case is a shallow beam with a flush end-plate and is tagged F1-5/8-3/8-10. In "F1", the F stands for flush and the 1 for one row of bolts at the tension flange (two bolts total). The last three numbers, all in inches, represent the bolt diameter, end-plate thickness, and beam depth, respectively. The geometric parameters for the end-plate are from Srouji et al. (1983) and are listed in Table 3-1.

The finite element model of this connection is a cantilevered beam and is three-dimensional as shown in Figs. 3-3 and 3-4. Symmetry about a vertical plane is utilized and only half of the structure is analyzed. Solid eight-node brick elements that include plasticity effects are used to model beam and column flange. The beam material is A572 Grade 50 steel (nominal 50 ksi yield stress); however, the yield stress of the plate is as measured in the experimental analysis. Elastic-plastic modeling of material stress-strain properties is used in this validation study, but a more complex model is used beginning in chapter 4. Contact elements are included between the end-plate and the column flange to represent the nonlinear behavior. Solid twenty-node brick elements that include plasticity effects are used to model the bolts and the end-plate. Constraint equations are introduced to make the bolt heads continuous with the end-plate. Bolt pretensioning is applied by prescribed displacements at the end of the bolt shank. These displacements are held constant throughout the loading. The column flange is assumed to be rigid and the nodes along the back of the flange are fixed against all translations. Finally, nodes along the symmetrical surface are fixed against lateral translations.

For the loading procedure, the bolts are first pretensioned. Next, increasing vertical loads are applied at the beam tip to induce an increasing bending moment at the connection. The stress in the bolt is tracked throughout the beam loading process. The beam loading is terminated to coincide with experimental results.

The accuracy of any complex finite element program is limited by the mesh refinement. Therefore, for all validation tests, a coarse and a fine mesh are considered. The terms “coarse” and “fine” are nominal and represent relative mesh refinement (i.e., the coarse mesh has half the number of elements as the fine mesh). For the F1-5/8-3/8-10 connection, the coarse and fine meshes are shown in Fig. 3-3 and Fig. 3-4, respectively. For this connection, the coarse mesh results are within 2% of the fine mesh results and the initial coarse mesh was considered adequate.

Figure 3-5 shows the effect of bolt pretensioning on the end-plate prior to vertical loading. The end-plate for this case is 3/8” and stresses near 14 ksi are shown. These stresses are von Mises stresses ,$\sigma_{vm}$, and are related to the principal stresses, $\sigma_1$, $\sigma_2$, and $\sigma_3$ through the relationship $\sigma_{vm} = \{0.5[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2]\}^{1/2}$. The effect of bolt pretensioning decreases as the end-plate thickness increases, but is negligible in any case at the ultimate limit state. Figure 3-6 shows the stress distribution in the proximity of the end-plate when the loading reaches about 33 k-ft. From Srouji et al. (1983), the yield stress of the end-plate is 51.90 ksi. Significant yielding around the bolt holes can be clearly seen. At this same loading, the end-plate separation relative to the column flange is shown in Fig. 3-7. The tendency of the end-plate to “pry” the bolt in tension is also seen by the bolt bending. Lastly, Fig. 3-8 plots the force in the bolt at the tension flange versus increasing load. Since the finite element results are in accordance with the experimental results, the experimental testing can be deemed accurate, and it can be concluded that the model is sufficient.

The second case considered is a deep beam with an extended end-plate and is tagged MRE-1/3-1 1/4-5/8-62. MRE stands for multi-row-extended or four rows of bolts at the tension flange in this problem. The last three numbers, all in inches, represent the bolt diameter, end-plate thickness, and beam depth, respectively. The geometric parameters for the end-plate are from Morrison et al. (1985) and are listed in Table 3-2.

Figure 3-9 shows the finite element mesh and bolt numbering scheme for the tension region of this configuration. Figure 3-10 shows the entire mesh near the end-plate. At the ultimate applied moment, the beam flange tends to slightly pull the end-plate away from the column flange. This can be seen in Fig. 3-11. The accuracy of the program in determining bolt forces can be seen in Fig. 3-12 and Fig. 3-13 which plot the forces for bolt #1 and bolt #3, respectively, versus applied moment.

## 3.3 CONCLUSIONS FROM VALIDATION STUDY

The major assumption associated with the *R-FLANGE* model is that the column flange is sufficiently thick such that it can be modeled as a rigid body. Since the *AISC Seismic Provisions for Structural Steel Buildings* (1997) requires that plasticity be provided almost entirely from one source, the program complies as all plastic behavior is limited to either the connecting elements (i.e., end-plate and bolts) or the beam itself. Limitations of this assumption are discussed in detail in Appendix A, where two conclusions are reached. For stiffness, the column flange should be at least as thick as the connecting end-plate to avoid a premature failure of the connection via bolt rupture, or a stiffener should be provided. Also, for strength, a design equation is provided to ensure that column flange bending does not control the design.

Since *R-FLANGE* can be used to generate models for almost any type of end-plate, the finite element results of these models were compared with experimental results to ensure the program's accuracy. Numerous configurations have been considered and accurate results have been obtained for all cases. These results include a case of the applied moment causing significant end-plate yielding and bolt forces that are recorded throughout the loading process. End-plate deflections and rotations are compared for the SAC specimens in the next chapter.

TABLE 3-1. Connection details for flush validation specimen.

| Dimension | Value |
|---|---|
| $g$ | 2.25 in. |
| $t_f$ | 0.25 in. |
| $t_w$ | 0.25 in. |
| $b_f$ | 5.00 in. |
| $p_f$ | 1.25 in. |
| $t_p$ (plate thickness) | 0.384 in. |

TABLE 3-2. Connection details for multi-row-extended specimen.

| Dimension | Value |
|---|---|
| $g$ | 4.482 in. |
| $t_f$ | 1.004 in. |
| $t_w$ | 0.375 in. |
| $b_f$ | 9.941 in. |
| $p_f$ | 2.403 in. |
| $p_b$ | 3.505 in. |
| $p_{ext}$ | 4.225 in. |
| $t_p$ (plate thickness) | 0.626 in. |