Outline
For Presentation of Connection Tests in the Welding Convention in Chicago

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Note:
The above requires about 22 slides. This number may be more than can be handled in a 20 min. presentation. I left out all stress distribution. It’s too much and not all could be presented.
Gentlemen,

The research on Connections for Welded Rigid Frames which I shall report to you is a part of a project on Welded Continuous Frames. The objectives of the project in general are the study of the carrying capacities of continuous frames. But before the frames themselves are studied it was thought advisable to study the component parts of frames, namely beams, columns and connections. What I shall report to you is a part of the results obtained on connection tests.

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Figure 1 shows some typical rigid frames. In these structures the various members are connected with rigid connection, thus compelling the columns and beams to work together in resisting the external loads. In the single span frame (portal frame) the column and the beam are joined together with a knee. Multi-span frames have knees at each end and interior connecting elsewhere.
The connections in the frames could be bolted, riveted and welded. The knees which were tested were welded (Fig. 1). In this figure you see various types of knees, such as square, bracketed and curved. The different arrangements in stiffeners in the built-up knee result in these various types in the three categories. These knees have been either extensively used in practice or have been suggested by the committee members or have been obtained from a literature survey.

I have stated above that the connections that have been tested are rigid knees. What do we exactly mean by rigid knee? The designer in analyzing rigid frames considers the angle formed by the centerlines of column and beam remaining constant as the structure deflects. But the knee is not a mathematical point. It is a part of the structure; it starts where the rolled sections end. The knee in transferring stresses from one member to the other is subject to deformation (rotations). It is the amount of rotations in the knee which decide whether or not the knee is rigid.

Therefore, it is of importance that we review in short the requirements for knees. (Fig. 9 and 10). In Figure 10, curve A gives the moment-rotation curve of the weaker of the rolled sections joined by the knee. The early part is the elastic part in which rotations are proportional to moments; then we have the elasto-plastic, and finally the totally plastic parts in which the section is completely plastic. The moment at this stage gives the "plastic hinge value, \( M_p \)" of the section.

This curve is compared to the moment-rotation curve of three knees (B, C, and D); knee B, for the same moment shows larger rotations than the rolled section and the maximum moment is smaller than the plastic hinge value of the beam.
We shall call knee B unsatisfactory. On the other hand, knee C is satisfactory. Knee D, although rigid enough, does not carry the maximum moment through large rotation and it will also be considered unsatisfactory.

The curves B, C and D are obtained by dividing the total rotation of the knee by the "equivalent length" of each knee. Such lengths are shown in Figure 9.

So, in order to be considered as satisfactory knees must be (a) rigid, that is, have rotations less than those of the rolled section; (b) strong, that is, must develop the plastic hinge value of the rolled section. As engineers, however, we are also interested in cost. The connection should have the proper strength and rigidity with the least amount of material and labor. Consequently, a third requirement is economy. A fourth requirement, which is of special importance in plastic design, is the ability of the knee to carry the maximum moment through large rotations.

The knees which were tested are shown in these two slides (Figs. 17 and 18). Those labelled A to N have an SB13 rolled section for both legs. Connection P consists of 8WF 31 as column, and 14WF 30 as beam.

Load lines were studied to obtain an idea on how the connections should be tested. Figure 19 gives some of the frames and load lines studied. In (a) and (b) with gravity loads the knees are subject to "compression." In (c) the single lateral force gives the load line shown. Here the left knee is under "tension", but such "tension" loadings occur very seldom under the combined effect of gravity and lateral loadings.

In (d) the left knee is under tension. Note, however, the extraordinary dimensions of this frame. It was decided, therefore, to load the specimens in compression, and to have Specimens A to N were tested either in a 300,000 lb. hydraulic machine or in a 300,000 lb. screw type machine. Figure 21 shows the test set-up in the 300,000 lb. machine. The load was applied through a loading fixture. This fixture was used in all connection test (A to N). A deflection gage used to measure deflections was used for this purpose is that the connection should be "as good" as the rolled-plate joint.
The principal measurements were of rotation in the knee for which 2 level bars were
used. Overall deflection was determined with a dial gage and SR-4 were
supported as shown. Level bars were used to measure the total rotation in the
knee. SR-4 gages were mounted at critical points to measure strains. The con-
nections were laterally supported as shown.

Fig. 22 shows the test set-up in the 800,000 lb. machine. In this figure
note the lateral support and the SR-4 gages to measure lateral forces. The level
bars and the deflection gage support can also be seen. A mirror gage was used to
measure the increase in moment arm of the external load as the legs deflected.

Figure 23 shows the test set-up for Connection P. The loads were applied
with a hydraulic jack and measured with a dynamometer. Both lateral and Longi-
itudinal supports were provided.

I have previously mentioned the requirements for rigid connections. Let us
now see whether or not the various connections meet these requirements. Figure
38 gives the total rotation in the knee and compares it to the rotations of the
two rolled sections joined by the knee. Obviously this connection does not meet
the rigid knee requirements. At all stages, its rigidity is less than that of
SW31, the weaker of the two sections. Moreover, it did not develop the plastic
hinge value $M_p = 1190$ kips; it is not strong enough. Figure 41 shows the distor-
tions in the connection at the end of the test. Why have the requirements of
the web not been satisfied, thickness and strength and rigidity not been met? The simplest answer is: because the yield took place in the web of the knee before bending yield occurred outside the knee.

This knee is unsatisfactory even for elastic design because before a stress
of 20 ksi is reached at the critical section a yielding takes place in the knee
and as you see the curves start deviating from a straight line.

The behavior of the Connections A to N can best be studied with Figure 51.
In this figure the moment at the knee (center of knee) is plotted against the rota-
tion in the knee divided by the equivalent length. When the various knee curves

Note that some of the curves are steeper than usual.
are compared to SB13, rolled section used, one can see that all of the connections developed in the knee itself the plastic hinge value of the rolled section. As for rigidity, all of the connections were except the Type 2 and SB which in the elastic part and early elasto-plastic part showed higher rotations. These extra rotations may increase the deflections in the frame about 5 to 10 percent.

However, some of the connections fail relatively suddenly, as soon as they reach their maximum load. They fail to carry the maximum moment through large rotations. Such connections are Connection B, C, G and H, and they may be regarded as unsatisfactory.

These curves give the moment at the knee. If, on the other hand, the moment at the end of the rolled section or the beginning of the knee is plotted against rotations, we obtain the curves shown in Figure 52. It is obvious that Connection B has not developed the $M_p$ value of the SB13 section at the beginning of the knee. The other three connections have developed the plastic hinge, although their behavior is different, as you see.

The place where the plastic hinge (or equivalent moment) should develop depends on the design requirement laid down by the designer. If the designer wants the $M_p$ value to be developed at the knee connection A to N are satisfactory. On the other hand, if the designer, in order to achieve further economy, wants the plastic hinge value to be developed at the end of the rolled section, some of the connections are unsatisfactory, namely,

Table VII summarizes the test results. The end column shows that if the second criterion of strength is used, Connections B, C, I, J, N and P are decidedly unsatisfactory under different moment diagram (longer legs).

An interesting subject to discuss shortly is the mode of failure of the various connections. Figure 71 shows the local buckling in the compression flanges.

Should a slide be inserted here to lead the listener to the other concept? Perhaps you could sketch on the board.
of the Connection P. However, this connection failed because of:

a. Extensive shear yield

b. Local buckling after extensive yieldings

c. Crack

The crack which developed is shown in Figure 72.

Figure 79 is a typical example of how the connections A to N failed. You see the extensive yield that took place in the knee and outside the knee. Yielding occurred both in the tension and compression zones. The connection failed finally due to buckling however by local yielding of the compression flanges which you see in this picture. At first the local buckling is symmetrical. Later on, as the deformations increase, one side of the flange deflects more than the other, thus bringing about the buckling of the web and the failure of the connections.

Figure 87 shows Connection B at the end of the test. Note the yield pattern and the local buckling in form of waves in the compression flanges of the built-up knee.

Lateral forces were measured with SR-4 gages mounted on the lateral supports (bars). These forces were found to be a very small fraction of the total force on the connection. Figure 78 shows the local buckling curve and the lateral force. Note that local buckling occurs more or less simultaneously with lateral buckling. This is the case not only in this connection but in all other connections in which the local buckling and lateral deformations were measured.

Figure 88 shows the permanent distortion in Connection B because of lateral buckling. Figure 96 is another example of permanent distortion due to lateral buckling. Note the bars used for lateral support and the SR-4 gages on them. Also note the level bar supports.
The following are some design recommendations:

A. Square Knees

1. Use a diagonal stiffener, as in Type 2 or 6B.
2. The thickness of diagonal stiffeners should be:
   a. About twice the thickness of the thinner flanges
      of the two rolled sections.
   b. About the same thickness as the thinnest of the
      flanges for knees similar to Connection L&M, Type 6B.

B. Bracketed or Haunched Knees

1. The slope of the haunch must be such that when the ultimate is
   reached the moments in various sections of the haunch are equal
   or smaller than the $M_y$, the initial moment yield for the sections.
2. The $M_y$'s for ordinary slopes at the haunch may be calculated with
   the ordinary theory.
3. Use stiffeners at points of internal thrust.
4. In bracketed knees the depth of the bracket should be equal to the
   depth of the section to which it is connected.
5. Use stiffeners to distribute direct forces such as external loads
   or internal thrusts and to support the web against buckling.
6. The stiffeners must be in general of the same thickness as the web.
7. The length $L$ of the stiffener, which should be enough to transfer
   the thrust to the web, may be obtained from the relation

   \[ L = \frac{tw}{w} \]

   where: $b =$ width of the rolled section flange.
   $w =$ web thickness of the rolled section.

1. [Handwritten note: See 61 above]
2. [Handwritten note: Suggest adding another web if diagonal is objectionable - further note suggested.]
3. [Handwritten note: Influence of staff in 8B is negligible (?) recommend type L?]
4. [Handwritten note: 1?]
5. [Handwritten note: 1?]
6. [Handwritten note: 1?]
7. [Handwritten note: 1?]