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Proposal for further work: corner connection studies, 24 January 1955

Lynn S. Beedle

LEHIGH UNIVERSITY
BETHLEHEM, PENNSYLVANIA

FRITZ ENGINEERING LABORATORY
DEPARTMENT OF
CIVIL ENGINEERING AND MECHANICS

File: 205C

24 January 1955

Lehigh Project Subcommittee
Structural Steel Committee
Welding Research Council

Corner Connection Studies

Gentlemen:

Attached you will find descriptions for two studies proposed for the project "Welded Continuous Frames and Their Components". These have been prepared by Dr. Schutz and reviewed by our project staff. In addition there is a summary of the committee's response to the questionnaire "Corner Connection Problems" dated August 9, 1954. Most of the comments concerned the problems placed before the committee. However, Mr. Grover has suggested the possibility of testing a large connection at low temperature to determine its plastic behavior (See Mr. Grover's suggestion at end of "Summary of Comments".) The committee's reaction to this suggestion is solicited.

During the planning of these proposed studies the comments of the committee have been kept in mind and it is hoped that a realistic program has been outlined. Mr. Weiskof's letter of August 31, 1954 which was sent to all members of the subcommittee expressed a reasonable viewpoint and the proposals presented herein are in agreement, we believe. The first, "Development of Design Procedure for Haunched Corner Connections", is a project of short duration which should result in a practical paper summarizing our knowledge on the behavior and analysis of such connections. The second proposed project, "Plastic Behavior of Built-Up Structural Steel Frames" is more extensive and would extend Lehigh's investigation into a new area which is of utmost importance to one of our sponsors. This second program would be directed toward problems in built-up ship structures which are found to be most urgent.

After you have been able to study these proposals, will you please indicate your approval or disapproval of each study on its individual merits and also indicate the order in which you think they should be attacked. It is possible that both studies might be undertaken at once. A return form is enclosed.

Sincerely yours,

Lynn S. Beedle
Assistant Director

FWS:bk

ENC:

Dr. L.S. Beedle
Fritz Laboratory
Lehigh University
Bethlehem, Penna.

I approve the following proposals:

Yes	No	Title	Order of Importance
		Design Procedure for Haunched Connections	
		Plastic Behavior of Built-Up Steel Frames	

Comments on Mr. Grover's suggestion of low temperature tests:

Other comments:

Signed

WELDED CONTINUOUS FRAMES AND THEIR COMPONENTS

Proposals for Further Work

Fritz Engineering Laboratory
Lehigh University
Bethlehem, Penna.

24 January 1955

Fritz Laboratory Report No. 205C.18

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Phase VI. DEVELOPMENT OF A DESIGN PROCEDURE FOR HAUNCHED CORNER CONNECTIONS

Since there are several reasons for the use of haunched welded connections in plastic design as well as in elastic design there is need for a simple yet accurate method of proportioning such haunches. The method should be such that it would fit into philosophy of plastic design but could just as well be used by the elastic designer.

A design procedure should be developed which would assure elastic behavior of the haunched portion of a frame even when the structure has reached the ultimate load condition. This will mean for most structures that plastic hinges have developed in the prismatic beam sections adjacent to the haunch at ultimate load. Baker has shown by such an approach that savings in weight of the main frame of as much as 10 percent can be achieved when the haunch has a length equal 1/20 of the span for a typical portal frame compared to the same frame having no haunch.

The use of haunches in plastic design may be necessary in order that rolled sections may be used for the prismatic beam sections of the frame. This condition may easily be encountered for long span portal frames.

For portal frames subject to a stationary primary load and an occasional secondary load, the economical solution may be a frame based on elastic design having haunches for the primary load and the use of its plastic behavior to meet the secondary loading. Haunches in such a structure should be proportioned so that they would perform satisfactorily during the secondary loading.

Frames designed on ultimate strength behavior having haunched connections which remain elastic will require less lateral bracing at the corners than the unhaunched frame.

The above discussion points out the need for a simple but sufficiently accurate procedure for the design of haunched connections in the elastic state. Such haunches may have either a straight or curved inner flange. There are presently available methods of analysis (Osgood, Bleich, Olander, etc.) for such connections. However, the majority of these have been so complex that their use has not been wide spread. For the range of practical haunch proportions, it is the considered opinion of our group that a simple, usable and yet sufficiently accurate design procedure can be developed which can be used by any designer who is capable of designing a simple beam.

OUTLINE OF PROPOSED WORK

Analytical:

1. Make complete survey of available methods of analysis.
2. Establish the practical proportions of haunched connections. (Straight and curved inner flanges).
3. Describe completely a simple method of analysis for bending and shear stress within the haunch for the practical proportioned haunch.
4. Investigate and report the percent error possible by the method of Step 3 as compared to the more nearly exact solutions.
5. Develop a design procedure.
6. Give several illustrative problems showing the analysis and design procedure for haunched connections from plastically designed frames.
7. Show how the design method can be applied to elastic design.
8. Make a study of the optimum haunch lengths of several typical portal frames where plastic design is used.

Experimental:

1. Design and fabricate two haunched connections (one straight inner flange and one curved inner flange) according to design rules developed in analytical phase.
2. Test the two connections listed in Item 1. These tests should demonstrate the ability to proportion haunches such at that they remain elastic while the adjacent prismatic members develop plastic hinges. They also will provide the opportunity to check experimentally the accuracy of the analytical methods developed.

Order of Work:

The work proposed herein is of such an integrated nature that it is felt that the entire outline of work should be completed and reported as a unit.

PLASTIC BEHAVIOR OF BUILT-UP STRUCTURAL STEEL ~~FRAMES~~ MEMBERS

The whole field plastic design as applied to structures formed of built-up sections needs to be studied. Frames of all welded built-up sections are commonly used as the skeleton of the modern ship. In this field, especially where conservation of weight is paramount as in naval vessels, there is good reason to believe that plastic design may have one of its most important uses. Further it is believed that if sound knowledge of the behavior of built-up sections were available, plastic design may well be extended to frames having spans much greater than may be covered by the largest of rolled beam sections.

Much of what has been learned about rolled beam sections can undoubtedly be extended to built-up sections; however, there are areas that need particular attention. Rules and procedures of design need to be established for prismatic built-up beam sections so that they perform satisfactorily in the plastic regions. Such rules would include methods of stiffening very thin webs and flanges such that local buckling does not occur.

Once the problem of the built-up beam sections has been satisfactorily answered, adequate methods of joining such members must be determined. This problem probably will be solved most easily by proportioning the connections so strong that the plastic hinges are forced to occur in the prismatic beam sections adjacent to the corner connection. It is proposed therefore that the first attempt at corner design for built-up construction be made on this basis. If such design becomes impractical because of analysis complications or because of excessive weight of the structure, it may be necessary to design the connections considering their plastic behavior.

In summary, this program is aimed at developing design rules which will enable those designers who are forced to work with built-up structural shapes to proportion their structural members so that full plastic strengths may be realized before buckling occurs.

OUTLINE OF PROGRAM

Analytical Work

1. Survey the available literature on the design of built-up members.

2. Survey the available literature on plastic buckling of structural shapes and elements with reference to built-up members.

3. Determine in what areas of built-up member design there is insufficient knowledge of the plastic behavior and by theoretical or experimental means establish the necessary knowledge.

4. Set up design rules or proposed specifications which will assure the full plastic behavior of the beams over a range of strains such that ultimate strengths predicted by simple plastic theory will be realized.

5. Study the available methods of elastic analysis of corner connections for built-up members.

6. Set up design rules for corner connections which will assure the formation of plastic hinges in prismatic sections adjacent to the elastic connection.

Experimental Work:

1. Plan and carry out such tests as are necessary to establish a knowledge of the plastic behavior of the various components which make up a built-up section as described in Step 3 in "Analytical Work" above.

2. Design and test a simple beam of typical built-up cross-section to establish the ability of members proportioned by the proposed rules of design to develop proper "plastic hinges".

3. Design and test a corner assembly of built-up members having a connection which will, according to the design recommendations, remain elastic while the adjacent built-up beams yield. This test would establish to some degree the validity of the proposed methods for corner connection design.

Order of Work:

While the description of the work in this proposal is wide in scope, it is expected that the first phase of the work shall be directed to the problem of ship structures. A detailed description of this phase would be submitted to the committee for approval after the first preliminary studies have been made.

CORNER CONNECTION PROBLEMS

At the last meeting of the Subcommittee a number of the remaining corner connection problems were reviewed. It was agreed that an outline of variables should be submitted for discussion and comment. Based on suggestions received, we would then submit a detailed program for criticism and approval by the committee.

The attached outline of variables (arranged according to "Phases") is therefore submitted to you. Where appropriate, space has been left for your comment at the end of each problem statement. It would be helpful if you would comment on the relative importance of the problem and suggest specific details where possible.

Phase I:	INFLUENCE OF DESIGN DETAILS	Types: 2, 2B, 4, 5A, 7, 8B, 15, 16 (a)	Shapes: (8B13, 8WF31, 14WF30) (b)

This phase has been completed and has been reported in Ref. 1. Analysis and tests involving 8B13 rolled shapes were completed.

Phase II:	SIZE EFFECT	Type: 8B	Shapes: 14WF30, 24WF100, 36WF230

Tests: Completed as of July, 1954

Analysis: Small amount yet to be done as part of the report.

Preliminary results are presented in the "Summary Report" (P.R.-Z). A final report on results is in preparation (Progress Report Y).

Phase III:	ROTATION CAPACITY	Type: - -	Shapes: - -

Tests: None planned beyond those required for other phases and other programs.

Analysis: To develop methods of predicting the required rotation capacity and to translate into rules for design use.

This study is part of a current dissertation.

Phase IV:	"TENSION" BEHAVIOR	Type: All	Shapes: All

Tension tests of connections which has been previously loaded in compression have been carried out on many of the specimens at Lehigh. A report on these tests was

- -

(a) On one test (P) a 14WF30 was joined to an 8WF31
(b) Connection Types shown on Page

(1) "Connection For Welded Continuous Frames", Progress Report #4 by Toprac, Beedle, and Johnston, Welding Journal, 1951, 1952

presented at the A.W.S. meeting in the fall of 1953. This paper should be published soon in the Welding Journal, and will also include results of "prime" connections tested in tension at the University of Texas. It would help in planning possible tests to know how frequently "positive moment" was encountered at connections in portals.

Comment:

Phase V:	WEB REINFORCEMENT	Types: Straight, Shape: (Select)

Va: Diagonal Stiffeners

As the stiffness of a knee varies, the distribution of the total rotation of the parts of the frame near the knee varies. The knee might be made so strong that very little rotation can occur within the knee proper thereby causing adjacent beam sections to undergo the entire rotation. In a connection with less web reinforcement, the flange and web are spared severe plastic deformation; but with too little reinforcement the connection will not develop the plastic moment.

The studies carried out under Phase I led to a recommended web diagonal stiffener size. A safe rule has been to use a thickness equal to that of the flange. A series of tests designed to check this recommended size would involve an estimated 4 specimens.

Comment:

Vb: Use of Doublers

This constitutes an alternate to Va, above. Doublers would be used parallel to the plane of the web. (Fig. 9 of Ref. 2) (Type 8C). As few as 2 or 3 tests would be adequate. In planning

(2) "Rules of Practice in Plastic Design", Intr. Report #26, by Beedle and Johnston, Fritz Lab. August 1954

the tests, use would be made of results of Phases I and II.

Comment:

Phase VI:	HAUNCHED CONNECTIONS	Type: Tapered (2B) Curved Type 4	Shapes: (Select)

Analytical studies followed by a modest number of tests appear to be adequate to investigate proper proportioning of haunched connections. Although, economically, the tapered haunch seems best suited for frames supporting a single loading condition (conventional design) there may still be a field of application of plastic design in the case of a second loading condition with a limited number of cycles. Appropriate studies are:

(a) Proportions of Type 2B connection to assure formation of hinges adjacent to haunch. (Thickness of inner flange, required depth at connection "throat")

(b) "Wedge-beam" construction -- behavior in frames under "primary" and "secondary" loading.

(c) Proportions of column-haunch assemblies with gradual (curving) transition from column base to girder splice.

(d) Reinforcement of curved knees by use of channels in lieu of inner flange plate.

Comment:

Concerning Type 4 connections (45° "bracket" type) a few tests have been carried out at Texas(3) in which the amount of stiffening was reduced. Type 14 connections appear suitable and the economic procedure will

(3) "An Investigation of Welded Rigid Connections for Portal Frames" by A. A. Toprac, Welding Journal, January, 1954

probably be to require elastic haunch behavior with hinges forming adjacent thereto.

Comment:

Phase VII:	SHIP-TYPE KNEES	Type: - -	Shape: (Built-Up)

The Type 16 Knee was tested as part of Phase I on the basis of application to ship structure stiffeners. Results were reported in Ref. 1. A different problem that has been mentioned is that of the knee in a main transverse frame bent. Due to the girder depth, this knee must be "built-up". Problems concern web stiffening in the vicinity of lighting or access holes. Analysis of this special application and tests, correlated with Phase VIII, appear to be important.

Comment:

Phase VIII:	BUILT-UP STRAIGHT CONNECTIONS	Type: 8C	Shape: Built-Up

Knees of depth greater than 36" have not yet been studied with regard to plastic behavior. (The study will be correlated with Phase VII) It would help in planning the programs to know a typical depth and flange width vs section depth ratio of such connections.

Comment:

Phase IX: ENCASEMENT Type: - - Shapes: - -

Since many steel frames are encased in concrete for various reasons it might be of interest to determine the behavior of the welded knee when encased in concrete. The type connection used might be one of those tested in previous phases of this project. Any studies would be correlated with lateral bracing studies, since it is expected that one of the principal effects will be to stiffen the connections with respect to lateral buckling.

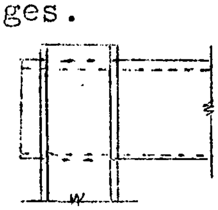
Comment:

Phase X: MISCELLANEOUS TYPES Types: 1, 9 Shapes: - -

Type 1 connections were tested in a program carried out at the University of Texas. From the results(4) the connections performed in very satisfactory manner and additional tests seem unnecessary at this time.

Comment:

The use of channels placed back to back (see sketch, Type 9) to form a rigid frame knee has been suggested by Amirikian. - - etc.It is believed that the characteristics of this type of connection could be established with a few tests. The double web thickness at the knee appears to afford considerable advantages. Aside from the connection itself it would be of interest to establish the behavior of the channel sections in the plastic region.



Comment:

A separate phase on the influence of shape of cross-section is not included because the associated problems are either a part of the above phases or the "Inelastic Instability" program (205E).

A study of connections using I-shapes has been mentioned previously. Some tests were done at the University of Texas. Because of the relatively greater web thickness, less web stiffening is required. Prior to additional testing it must be demonstrated from the over-all point of view that it would be economical to use I-shapes instead of WF sections. As against the fact that I-shapes are heavier for a given section modulus and that tapered flanges are more difficult to connect there must be weighed the improved performance of knees, the increased resistance to shear and to local buckling, and the increased shape factor.

A separate phase on Lateral Bracing is not included because it is considered as part of a broader study of the lateral support requirements for all parts of rigid frames (205H). However, data is collected on each test, and each study is planned keeping this variable in mind.

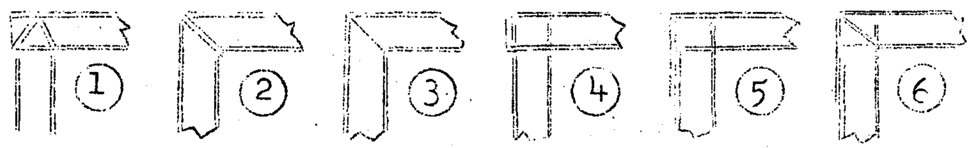
Similarly, performance of connections under the Repeated Load or Impact are not included as individual phases but are considered as parts of programs of broader coverage (205G, 205K). In the one case the aim would be to determine how many cycles of load (based on plastic design) a connection will withstand. Solution of the impact problem should find application in structures proportioned to withstand blast load.

Comment:

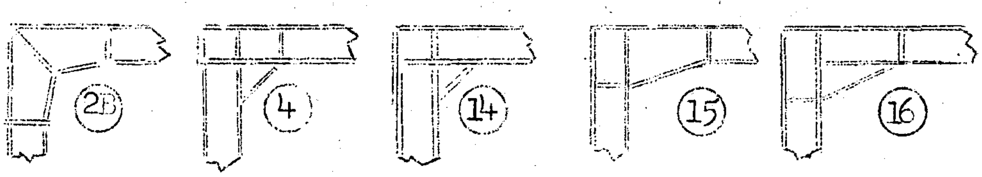
Two copies of this statement are furnished. As suggested at the beginning, we would like you to return one of them with your comments.

F. W. Schutz, Jr.

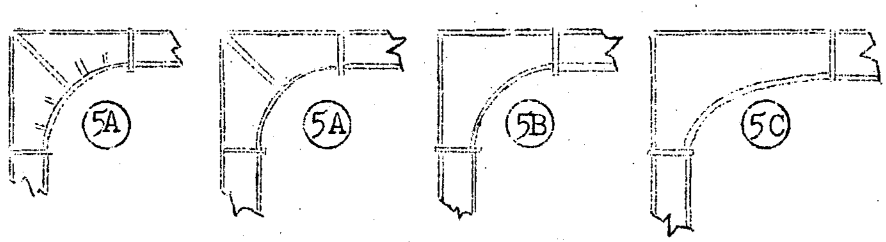
Lynn S. Beedle



Square Knees



Haunched Knees



Curved Knees

PORTAL FRAME KNEES

Summary of Comments on

"Corner Connection Problems"

from Members of Lehigh Project Subcommittee

PHASE IV - "TENSION" BEHAVIOR

Mr. Larson - "Flat roof, light loads, positive moment under large lateral forces."

Mr. Higgins - Actual "positive" moment at knee possible only when frame is heavily loaded with horizontal forces and lightly loaded vertically. For their case plastic design has little advantage over elastic design unless column bases are fixed, which is not the usual condition. Hence further study of tension only academic interest.

PHASE V - WEB REINFORCEMENT

Va: Diagonal Stiffeners

Mr. Boardman - I favor this series of tests and give it a priority rating above Vb.

Mr. Grover - There is one other matter which has been drawn to my attention, namely that we have not developed a really rational method for designing web reinforcing for a knee. If any additional information could be developed readily in this connection, perhaps in conjunction with other tests, it would be nice to carry this work further. However, it seems to me that this is the least important of the unfinished work, from a practical viewpoint. Information that would permit a more exact analysis to proportion such web stiffeners at knees, would not save a great deal of material or cost of fabrication, because in most cases, I believe, such a stiffener would have to be fitted and welded, and would not cost very much to make it a little larger than necessary to fill the requirements of the rule of thumb method that is now being used.

Mr. Larson - I think thickness of diagonal stiffeners could be reduced, possibly to web thickness.

Mr. Higgins - I would not give this study a high priority. But, if a simple rule could be proven up with a few tests, which would reduce the size of stiffeners, it would be worthwhile in the case of larger rolled shapes. The cost of the

Mr. Higgins (Cont.) - material is minor. The cost of the welding required to develop large stiffeners could become substantial and use of an unnecessary amount of welding should be discouraged whenever possible.

Vb: Use of Doublers

Mr. Boardman - Worth doing.

Mr. Larson - For light frames doublers may be sufficient but a large area of doubler would require interior attachment.

Mr. Higgins - I have no great enthusiasm for this study. If it is carried out I think we should investigate how much space can be left between the edge of the doublers and the flange fillet without seriously reducing their effectiveness. Also we should study the effect of using but one plate (on one side of the web).

Mr. Grinter - I have given some attention to your release of August 16 covering the subject of "Corner Connection Problems". It has long been my belief, based upon the tests that I performed at Illinois Institute of Technology, that a better knee joint than at present exists could be designed. Plastic flow takes place strongly at the inside corner, and this is very frequently a matter of web or stiffener failure. Stiffeners do not necessarily buckle, but they merely flow due to excess compression at the inside cover. I am inclined to believe that a study of this corner condition might lead to the use of a web thickener of very limited area that would accomplish the result of reducing the high stresses at the right angle corner. Unless I am mistaken, this solution could produce a more rigid corner for many designs than the introduction of stiffeners.

PHASE VI - HAUNCHED CONNECTIONS

Studies (a), (b), (c) and (d)

Mr. Boardman - I don't see need for curved knees except for aesthetic reasons.

Do (a) - Highest priority
Do (b) - Next

Mr. Grover - I think it is very important to keep in mind that architectural and structural engineers designing rigid frames composed of comparatively deep sections and of considerable span-length seem invariably to use haunched

Mr. Grover (Cont.) - knees. The reason for this is partly one of elastic preference, and I believe that designers have felt that there should be some preference from a technical or structural design viewpoint, whether there is real justification for the technical preference or not. Whatever may be the reason, I believe that a good many designers, if not a large majority of them, will likely continue to use haunched knees for rigid frame spans of comparatively great length.

It does not seem to me that we have obtained as much information as would be desirable for such knees of long-span frames, especially if they are to be designed by the plastic method and the designer would like to see the moment-rotation-curves run out fairly well rather than dropping off as rapidly as has been the case with most of the tests. Therefore, I think careful consideration should be given to the matter before it is decided that no more work is needed in the investigation of the behavior of haunched knees or connections.

Mr. Larson - Do not believe tests of these types desirable.

Mr. Higgins - Part (b) should check with Columbia program first.
Part (c) how would this fit into plastic design?
Part (d) I doubt that a small program would prove much about the use of channels.

PHASE VI - CONCERNING TYPE 4 AND 14 CONNECTIONS

Mr. Boardman - It should be determined whether 2B or 14 is the more economical.

Mr. Larson - Type 14 connection is worthy of consideration.

PHASE VII - SHIP-TYPE KNEES

Mr. Boardman - Make if ship people want them.

Mr. Grover - Also, we should keep in mind that the Bureau of Ships of the Navy Department has indicated that they would like to have some specific information regarding the behavior of the details such as they have used customarily in designing connections between beck beams and deep side frames, for example in an aircraft carrier.

Mr. Vasta - There are several problems involved in this project which are of particular interest to the Navy and which have not yet been solved. These problems stem from unique situations which the structural engineer finds in ship design. For example: In the design of combatant ships, where weight reduction in structure is of prime concern, the designer prefers to use built-up sections where close control may be kept on the size of web and flange plates. Experience has shown that very thin webs in girders are adequate for shear strength provided there is sufficient stiffening to prevent buckling, and the resultant structure will show a weight saving. At times, rolled sections of the size required are not commercially available, thereby making built-up sections necessary. Factors of safety are very low compared to land-based structures and utilization of plastic strength does present an advantage.

It is for these reasons that we wish to have the corner connection problem extended to include built-up sections. However, if you feel that the experimentation completed to date may be applied to built-up knees, such as occur on aircraft carrier transverse bents (depth to thickness ratio of webs ranges from 192 to 480 and knees with large access openings) then no further laboratory work is needed. An alternative might be to do some of the work in the "Inelastic Instability" program (205E), which we also consider very important. In any event, the corner connection problem should not be considered completed without at least some additional analytical work so that the knowledge we have acquired to date may be useful to the Naval Architect and other engineers concerned with large and unusual structures and where the plastic strength theory may find its greatest application.

Mr. Larson - Desirable to Navy group.

Mr. Higgins - No comment, except that web stiffener design at access holes seems to be to be an extremely specialized problem.

PHASE VIII - BUILT-UP STRAIGHT CONNECTIONS

Mr. Larson - No established ratios. May be desirable at some later date to study this relationship.

PHASE IX - ENCASEMENT

Mr. Boardman - Certainly it should be determined whether the encasement can safely be assumed to prevent lateral buckling of the steel.

Mr. Higgins - Could we hope to prove much with one or two tests? A more typical case would be that shown in sketch:

Brick or concrete block masonry exterior wall carried up to eaves <u>in lieu of</u> sway frame at haunch.

Mr. Larson - Only practical if limited to encasement for fireproofing.

PHASE X - MISCELLANEOUS TYPES

<u>Type 1</u>

Mr. Boardman - Make no more tests if previous results are convincing.

Mr. Higgins - I agree

<u>Back to Back Channels</u>

Mr. Boardman - Make if Amirikian wishes.

Mr. Larson - Rather impractical

Mr. Higgins - Eccentricity of loading with respect to the shear center of each member could be the over-reducing variable. Shear stress in web not likely to be critical. Warping, due to inability to keep loads on shear center, much more critical.

SEVERAL COMMENTS APPLIED TO THE CONNECTION PROGRAM IN GENERAL

The reply of Mr. Weiskopf can be summed up by his closing sentence, "In brief the corner connection investigation should be brought to a conclusion as a job well done and the efforts of the staff devoted to other work".

Dr. Johnston wrote "I am inclined to agree to some extent, at least, with Mr. Weiskopf and suggest that no further laboratory tests would seem urgently required at this time for your phases 1 to 6 inclusive.

With regard to phase 7, ship type knees, I recall that some concern was expressed by Navy representatives over the fact that ship type connections were not included in the program. In view of the very substantial support you are getting from this direction I think that serious consideration should be given to some work on types of connections in which they are particularly interested."

Mr. Webb wrote "In accordance with your letter of August 16th, enclosing copy of August 9th statement entitled "Corner Connection Problems", we have gone over this report and we agree with the comments given in Mr. Weiskopf's letter to you of August 31st.

Tests seem to have been made on all kinds of corners and further tests would only emphasize minor points. Time could be spent to better advantage, we believe, on other research problems."

Mr. Grover has suggested an additional problem which was not included in the original list. His comment is as follows:

> "Another thought that has occurred to me is that it would be very desirable to test at least one large knee at a considerably colder temperature than the room temperature that has been used for the tests to date. It was very gratifying to find that the 36-inch sections behaved so well, but there will probably always be some doubt in the minds of the people who are aware of the possibilities of brittle fracture, as to how these heavy deep sections would behave in cold temperature surroundings".