Closing session

CLOSING SESSION

Chairman : Dr. D. SFINTESCO

D. SFINTESCO :

I wish to thank all of you for your participation in the sessions held during these two days. In this closing part of our colloquium, the session chairmen will try to summarize the very interesting presentations of reports and the lively discussions we had on some subjects, thus drawing the conclusions of our meetings.

The chairman of the first session, Prof. Massonnet, had to leave earlier today. He asked me to present his concluding remarks.

D. SFINTESCO (for Ch. MASSONNET) :

The first working session was devoted mainly to the determination of residual stresses in hot-rolled members or in members fabricated by welding. The first paper by Tebedge, Chen and Tall, entitled "Strength Behavior of Heavy Welded Columns", contains theoretical and experimental analysis of the behavior and the strength of heavy shape columns built-up from flame cut plates. Comprehensive experimental investigation was performed to determine the strength and the behavior of one particular heavy built-up shape, H23 681 ACM A36 steel. The experiments included :

1) *measurements of yield stress through the cross section*
2) *measurements of residual stress distribution across the width and through the thickness of the component plate by the slicing method which involved corresponding longitudinal cuts*
3) *stub column tests*
4) *full-size column tests.*

The column tests probably break the world record of buckling tests.

As there was a flat end condition at the low end and some measured rotation was allowed at the other end, it is difficult to compare the collapse load with the theory. However, the three-dimensional theoretical analysis involving the effect of residual stress, yield strength variation on the cross section and initial out-of-straightness in the two principal axes were performed on computer and compared with experimental data. The two main conclusions of the study are : 1) because of the particular pattern of residual stress distribution in the cross section as well as the initial out-of-straightness in the two principal planes of such heavy shape columns, biaxial bending column analysis is needed in order to predict accurately the load-deflection behavior. The strength of heavy shape columns built-up from flame cut plates is found to be higher than those of lighter welded counterparts.

The second paper by Dr. Young, entitled "Residual Stresses in Hot-Rolled Members, attempts a thorough investigation of the residual stresses in I sections due to severe cooling after hot rolling. Dr. Young made comprehensive survey including a large number of previous measurements and containing most available results on British universal beam and column sections, in order to establish typical patterns for subsequent inelastic buckling strength calculations. He shows that these results are different from the american ones, especially for the residual stress distribution along the web, which he found parabolic instead of constant in american profiles. These differences are due, according to him, to different practices in particular in the cooling bed, and to cold straightening.

The third paper by Alpsten is entitled "Residual Stresses, Yield Strength and Column Strength of Hot-Rolled and Roller-Straightened Steel Shapes". The main purpose of the investigation was to study the improvement in column strength resulting from rotarized procedures. The rotarizing changes the residual stress distribution and may also attack the mechanical properties. The investigation was both experimental and theoretical. It included a comparison of residual stress, mechanical properties and column strength of four lots of HE 200 H shapes, all taken from the same heat. One reference lot was taken as rolled with no straightening. The three others were subjected to rotarizing treatment of increasing amplitude. These treatments were simulated theoretically and the maximum column strength was both obtained through buckling tests and by computer simulation taking into account the effects of non symmetrical residual stress, variable yield strength, initial out-of-straightness and eccentricities. The investigation showed that the maximum column strength may be increased by about 20 % due to suitable rotarizing procedure. It is suggested that this improved column strength of rotarized rolled members be considered in design by assigning the adequate column curve to this type of members.

The fourth paper by Brozzetti has for title "Effect of Welding Parameters on Simulated Built-up Column Strength". It contains two-dimensional contour maps of residual stresses in welded profiles and in the thick plates, either shear cut or flame cut, used in establishing these profiles. Residual stresses in these plates due to depositing weld seams on their central part are analysed separately. From these residual stress patterns, theoretical buckling curves for these welded I profiles are derived by the modified tangent modulus theory and conclusions are drawn regarding the effect of welding parameters. It may be observed that the theory used does not give a completely accurate picture, because it neglects simultaneously the Shanley effect and the effect of the geometrical imperfections.

The fifth paper by Prof. Lee entitled "Buckling Strength and Design Guide of Welded Linearly Tapered Column", falls somewhat outside the framework of this working session. The columns considered are H shaped sections with a linear variation of the cross sectional depth, fabricated by welding only on one side of the web. The specific content of this paper are :

1) *analytical elastic buckling solution of tapered columns*
2) *residual stress measured in tapered column specimens welded from both shear and flame-cut plate elements*
3) *analytical inelastic buckling solutions of tapered columns by considering the residual stresses*
4) *formulation of design guides including effective length factors for centrally loaded tapered columns.*

The sixth paper by Nylander has for title "Effect of Initial Stresses on Plate Buckling and Buckling of Box Columns". The plate buckling theory is based on a model for the study of the post-critical behavior consisting of a plate acting only in plate bending and a number of strips taking the membrane stress only. It was presented at the Amsterdam IABSE Congress. In the analysis of buckling of the welded box column with quadratic cross section, it is assumed that the effective

cross section consists of four angles with a flange width being equal to the effective width of the composed plates at the failure load in plate buckling. Numerical results of the calculations are given by diagrams which show that the influence of the initial stresses is of great importance. To be evaluated, these results should be compared by other more refined approaches of the same problem obtained by Klöppel, Skaloud and others.

The seventh and last paper by Dwight is entitled "Prediction of Residual Stresses caused by Welding. The paper shows how the longitudinal force in a weld may be estimated from a knowledge of the heat input or the size of the weld. With this information, it is relatively easy to predict a pattern of residual stress in a fabricated member. The formulae presented are appealing by their simplicity. They are not applicable to thick profiles. But, if their validity is confirmed by extensive comparison with actual residual stress measurements on welded profiles, they should constitute a convenient guide for the establishment of the residual stress pattern in new shapes of welded profiles.

T.V. GALAMBOS :

In my session there were two kinds of papers : one group of papers dealt with the determination of the ultimate strength of columns under a variety of conditions imposed by imperfections, residual stresses, crookedness, and so on and these papers were the ones by Young, Mazzolani and Fujita. These papers have really a great deal in common in that they all end up with curves which predict the behavior. The paper by Fujita was on H shapes and rectangular solid shapes and it differed from all of the other papers that were given here in that he introduced imperfections or initial eccentricity in the laboratory deliberately. There were specific pre-set initial deflections which were given to the columns which were tested and analysed. The method of analysis was a finite element analysis and he had subdivided his column length into a rather large number of elements. The paper by Young dealt with the study of British shapes and in contrast to all of the other analyses that have been performed in the other papers, he used the numerical differentiation technique rather than integration starting with the deformed shape of the column. In Fujita's paper a variety of effects are considered and four instead of three standard column curves are arrived at and a somewhat different column selection table was presented then as given in the standard European curves. The paper by Mazzolani dealt with the Italian shapes and their comparison with the European column curves. Residual stresses were studied as well as the initial imperfections. The paper ends up with a comparison of the predictions by the analysis vs. the European curves.

The other three papers concerned diverse topics. The first one that was presented was the paper by Leites and as an academician I enjoyed it a great deal. It dealt with the elastic large deflection problem but I think that its relevance to what this group is trying to do is somewhat limited. The second paper is the paper by Mateescu from Rumania and it is a very interesting paper in that it deals with the elastic lateral torsional buckling of elastically restrained columns which are loaded through the centroid rather than the shear center. The differential equations are developed, boundary conditions are given, and the solution is then described as a solution of the differential equations by numerical computer techniques. The interesting thing about this paper is that there are a number of charts given that permit the designer to analyse his problem quickly. The last paper is on an odd topic, namely fire and it was the paper by Mr. Witteveen who described the work done at his laboratory as part of the European study on the performance of columns at elevated temperatures and the major point that I got out of that paper was that it you could treat the fire problem as a time independent problem in a limited sense. This is the summary of the description of the work. While I have the podium here I would like to say a couple of things that I have observed about the work here and that I would like to plea for. I have been in the past year engaged in trying to write a probability based code for steel structures. In doing so I have had to root through millions of reports and trying to tie down test results.

For the sake of your successors and the younger people who are coming on, please document everything. Even though the information to you may be irrelevant and you have proved the point you want to make, somebody else may need this information vitally and it is very difficult to come by. The second point I would like to make is I would like reinforce the talk that was given by Mr. Marincek and also by Mr. Barta. Let us identify the major things and look for them. Thank you.

F. NISHINO :

The third session was divided essentially into two groups. The first three reports are concerned on the analysis of biaxially loaded columns whereas the three remaining reports are mainly concerned on design of columns, with introduction of the concept of probability in the last two papers. In the first paper presented by Gaylord, an analysis of beam-columns in uniaxial bending was discussed and then the same technique was extended into the biaxial bending problem. A column is integrated from the point of the maximum deflection towards both ends under a constant thrust. The stability criterion is the maximum end eccentricity which would result by changing the magnitude of the maximum deflection. It is easy but time consuming to find out the maximum eccentricity by changing the magnitude of the deflection and integrating each time for an end eccentricity. Instead an auxiliary equation is introduced by differentiating the equilibrium equation. The problem of finding the maximum eccentricity by changing the initial value of the deflection has, thus, been changed into a problem of solving two simultaneous equations which is an interesting scheme and contributed in reduction of computing time without any loss of accuracy.

Lindner used, in the second paper, the Ritz method with displacement function given by polynomials to study the ultimate strength of biaxially bent columns. An equilibrium position has been determined by the stationary condition of the total potential energy and then the stress distribution has been checked for any possible violation of stress-strain law. If it is violated, correction is made and the procedure is repeated until both the equilibrium and the stress-strain law are satisfied. The ultimate load is determined by observing the maximum point of load vs. deflection relations. The residual stresses and the geometric imperfections are considered in the analysis.

In the third paper, Vinnakota presented a summary of studies on restrained columns under biaxial bending utilizing finite difference technique. One of the points of theoretical interest is that the equilibrium equations are written with respect to an arbitrary system of axis. With this, some of the complexity which arise from the shifting of the location of the shear center and the centroid with the penetration of yielding can be avoided. Another point of interest is the springs attached at both ends. With these springs, the entire system becomes stable even when the column itself is already in an unstable equilibrium and therefore the simpliest ultimate strength analysis can be utilised ; that is, the load can be increased up to the maximum point of the load vs. deflection relationship of the column without any instability in numerical computation.

In the third paper Steinhardt presented design formula for columns made of aluminium alloy, which has been developed at Karlsruhe and will be employed in German specifications. The formula was derived principally based on the analysis of eccentrically loaded columns. It was pointed that the formula predicts closely not only the strength of centrally and eccentrically loaded columns which fail by excessive bending, but also for the torsional flexural buckling, and that it is more rational even compared with the existing formula in German specifications, DIN 4114. It was also pointed that in spite of the fact that there are significant differences in stress-strain relation and in residual stresses between aluminium

alloy columns and steel columns, the formula derived for aluminium columns can also predict closely some of the column curves of ECCS.

For the last two papers I had some difficulty to take notes during the presentation and also I have difficulty to read French. I am rather afraid that there might be some misunderstanding in the 5th paper presented by Massonnet. The results and the conditions of CIDA research conducted at the University of Liege on stability of tube-and I-shaped aluminium alloy columns were presented. A similar computer simulation technique as used in deriving the column curves of ECCS has been used in order to estimate the strength of the columns with due consideration to the statistical variation of parameters. The theoretical study has been substantiated by a series of experiments sufficient in number to make use of statistical treatment. It was found that the stress-strain diagrams of aluminium alloys studied could be represented by Ramberg-Osgood curve. The dispersion in mechanical properties is small and two stress-strain curves could be sufficient for the practical design purpose for six alloys studied. The influence of cross sectional shapes for the strength curves was found very small.

In the last paper, Sfintesco and Djalaly treated statistically a large number of test results on simply supported axially loaded aluminium columns, and established non-dimensional column curves for the probable collapse limit with a constant probability of failure. The dispersion was also presented as a function of slenderness ratios which would serve as the basis to define variable safety factors in order to have constant reliability. The discussion followed for the last two papers indicated that the probabilistic approach is an important aspect for better design of columns and that it will be one of the topics that need continued investigations.

O. STEINHARDT :

The fourth "working session" in its first group Kato, Finzi and Nishino has dealt with problems of tubular struts, with centrally compressed built-up struts and with ultimate strength of box columns. This special cross sections may be designed on the conception that -with introductions of special imperfections- they could have the same safety factor as tension bars. The behavior of the component-struts and fasteners in built-up sections further has to be investigated. The influence of welding maybe more important for struts with low eccentricity of axial loading. Hot rolled wide flange columns need another consideration than welded, these latter have a more pronounced reduction in buckling stresses. The second group of this fourth session, manifesting some profound basis problems of buckling, dealt with by the colleagues Marincek, Barta and Carpena led the discussors to the opinion that mathematics and nature, computer and brain are to distinguish and that history and practical experience give some advice what engineers way into the future has to be. That, in my opinion, is the main question, namely to find out from the numerous influences (or parameters) the most essential ones. For the world wide standardization there must be developed in the next future some uniform and approximatly exact buckling curves for the 4 or 6 buckling situations in light or heavy rolled and welded cross sections ; by good will, that could be a short-time-conclusion.

L.S. BEEDLE :

The fifth session dealt with the European Column Research with the heavier shapes of Europe. These were studied at Lehigh and with the probabilistic, statistical, and load factor considerations.

How many here have seen a centrally loaded pin-ended column in a structure ? How many have seen one ? I have seen about 50. They are in a bridge in Czechoslovakia, centrally loaded, pin-ended columns in a structure, not in a test machine. Are there others ? Probably very few.

Well, all of this concern about a rarity is probably for two reasons :

1) *The fact that column design in most cases makes use of an interaction formula one end of which is the case for M = 0. Until there are some alternates, this will be with us for a while.*

2) *Another reason is because of a comment the cynic once made that we do research on those problems for which there is a hope of getting a solution !*

Sfintesco reported that the wide variation in column formulae led initially to the ECCS program and he outlined the approach that was taken.

Tebedge showed the good correlation at $L/r = 95$ and something less than implied at $L/r = 50$ by the ECCS curve for these heavier shapes of this European series that were tested in the U.S.A.

Bjorhovde presented the probabilistic approach applied to the parameters such as e/L, residual stress, yield point stress variation etc.

Strating described the Monte-Carlo method to predict column buckling curves and showed them to be in reasonable agreement.

Cornell distinguished between the variables that could be measured and those that had to be assumed or that he believed had to be assumed.

Galambos presented what he calls a simplified method of column design. Whether it looks simple or not, it does contain the key elements of what is needed for the "load-factor" design method.
The discussion brought out a number of things that should be summarized :

1) *The suggestion that we should "calibrate" the computer programs as developed in Europe and in the United States to make sure that when one puts in the same material one gets out the same maximum strength. Also this would apply to calibrating the influence of various parameters.*

2) *When we talk about the out-of-straightness of columns, we should use values that would correspond to what actually exists in buildings.*

3) *The need for data on variation of the influence of the thickness of the shapes, and the end restraint effect, and the out-of-straightness factor.*

4) *Many other needs were outlined later the following session by Bill Milek.*

I sensed from the discussion that these three areas are open.

1) *How to cope with a new column shape, the introduction of a new method of fabricating, and a new type of steel.*

2) *The use of column tests. On the one hand, they are used to confirm a theory, in which case we study the variations due to yield point, geometrical variations, residual stress, and out-of- straightness. On the other hand the column tests are a statistical basis for empirical column curves and then probabilistic approach is used considering some of these same factors as in the theoretical approach to see if the empirical curves can be justified.*

3) *How to apply the results to design. In the probabilistic approach, how will this in fact be applied to design ? How will we apply the design curves like curve d and curve 3 which are below what existing specifications would call for ?*

D. SFINTESCO :

The sixth session was dealing with what I would call the final point of the research on column strength : the results which are directly interesting for practical design. In the first paper by Marek and Skaloud we had a description of the current CS specifications and also indications on the new ones which are being prepared now. We have seen that they apply the probabilistic approach and we could also notice that they are adopting the European curves, at least the two upper ones, but they found that the lower curve was in their opinion too conservative.

The next paper by Bjorhovde and Tall on the development of multiple column curves deals with the American attempt to introduce multiple column curves in order to reduce the deviation between real and design column strength. In the first part the paper gives a review of the deterministic investigations on maximum strength of different shapes. It is followed by a description of the probabilistic computation studies. It shows that in the United States both approaches are now being considered.

The third paper by Beer and Schulz on the basis of the European column curves which has been discussed just before, shows the results which have been now adopted by the European Convention. I shall not go into the description of this particular paper. I wish to point out that these curves which have been developed have been found satisfactory enough for being approved by the European Convention and that they are already adopted in current codes or in codes which are submitted for approval in several European countries, at least in Belgium, Italy, Norway, and probably within a short time in several other countries. This means that all these countries have accepted the concept of the multiple column curves and also of the different yield points as explained in the paper of Carpena in the session before.

Dr. Dwight's paper, a very comprehensive and interesting paper pleads, as the title says, for interpreting the ECCS curves by means of the Perry-Robertson formula. I must say this demonstration was very convincing and tempting by the arguments which have been given. However, I would point out to the remarks of Prof. Massonnet and myself : there may be also satisfactory interpretations with other theories and other formulae and if one looks at the experimental results it is almost always possible to adjust more than one theoretical approach. This is probably even more so if one thinks that most column curves including those of the ECCS contain amounts of empirical arbitrary and comprise decisions, so it is always possible to adapt them to various theories. I am afraid that several countries may prefer to keep the theories which are familiar to them.

Prof. Vogel's paper goes a step further by going from the inexisting pin-ended column to the real structural member. I think in some way his concept can be already found in some theories which have been developed but it is extremely interesting to have this suggestion which opens a practical way for the application of the basic column curves to structural members in compression.

The last paper, of Johnston, is analysing the step from the standard or code maker to his victim who is the designer. There is of course a significant difference between the first who may want, and probably have, to refine design rules in order to attain a good approach of the actual carrying capacity of the column and the second who may hate complexity by still being interested in material savings. The author suggests a very simple formulation in good agreement with the curves proposed on both sides of the Atlantic.

Finally we had a most interesting report of Mr. Milek reflecting the position of CRC and we are must indebted to him for having reported here on the position of this body. This shows at the same time an open mindedness towards findings from elsewhere and a rather prudent position on some points on which the CRC does not wish to commit itself as long as research is not enough completed.

As a final remark I'm saying that in general we can see from these papers a tendency to the general acceptance of the fact that multiple column curves are necessary for a close approach of the carrying capacity of columns of various shapes, sizes and fabrication procedures.

The problem of the resulting complexity for the designer is also a general concern. A good philosophy may be even for standards to give the means of a refined method for maximum material savings and an envelope of very simple formulae or tables which can be used depending upon the choice of the designer and of the object of the study.

Well, now gentlemen, this closes the summaries of the six sessions. I would like now to ask Prof. Johnston if he may say a few words as closing remarks on this symposium.

B.G. JOHNSTON :

As we went through these two days I was struck by the fact that various persons touched on what I would like to call 4 different worlds. First of the world of theory. Within the world of theory we can theorize on theoretical columns and come up with column formulae for either a perfect or imperfect column. Then there is the world of the testing laboratory. Now, with regard to the testing laboratory column we sometimes make the mistake of thinking of it as a real column. But it is almost as far from the world of reality as is the theoretical column. We can learn a great deal more about the testing laboratory column than we can about the real column. Thirdly there is the imaginary real world. Our ideas about the real column in the real world can be formulated on paper but they still are essentially imaginary. Finally there is the real world and the real column in it which involves all of the variables inherent in the problems we have been talking about and in addition the effect of walls, windows, load uncertainties, and many other things. I think it would be well if we tried to be very careful as to which world we are in when we are talking about columns.

D. SFINTESCO :

Well gentlemen, before closing this last session I think I should like to make three remarks. First of all at the end of these presentations and discussions we can say that this colloquium has been a success as expected. It may not be unappropriate to think once more that it was initiated by Prof. Beer. Its success is of course due to the large participation of many outstanding personalities from the world of research in this field. We had an impressive number of very interesting papers and of course all these papers and the discussions have to be published in the proceedings of this symposium. No decision has been made yet on the practical way to produce them but in any case we take care to have them. So in this respect I should like to announce two deadlines. The first one does concern myself, I would like to commit myself to send a letter with precise instructions as to the way in which the authors can contribute to these proceedings. I shall try to do it not later than the 15th of December. The authors will be asked to contribute to the practical preparation of the proceedings by giving once more their paper, probably in the standardized form. Thus in most cases they would have to be retyped. It will be easier for every author to retype his own paper than for somebody else to type all of them. We should like to have these new versions sent by the authors before the end of January. Of course there will be a difficult problem about the transcription of the discussions. We have no solution yet and we shall look for that.

Another point : we said and I think everybody is convinced that this colloquium was very useful. Therefore it is very natural to think that another one should be held after some time. This was the first time that people from several areas of the world have met together on this particular problem. As we have seen for instance from Mr. Milek's report, there are lots of gaps in our knowledge. There are some problems for the pin-ended column still to be studied, but a most important point is of course the real bar within the structure. I think the next colloquium could

be devoted to these two aspects : completing the knowledge on the pin-ended column and, probably even more important, dealing with the real member in the structure. In my opinion it would be quite reasonable to think of such a meeting in three years from now.

Now my last words will be to thank the authors and the discussers for their outstanding contributions. To thank especially all those who have travelled from far to come for this special meeting. I may be allowed to express also thanks to those of my staff who helped organize and hold this meeting successfully. Now a last personal remark. I took the liberty to prepare for all foreign participants a small personal present which you will find just in going outside from here as a souvenir from this colloquium. An dnow I am pleased to pass the chair to our host Mr. Wahl.

L. WAHL :

Gentlemen, we are now at the end of this meeting and I have the task of closing a meeting which has lasted for two long days of work. I suppose that many of you are very tired already but I hope nevertheless that none of you has been overstressed. You have listened to about 40 different contributions and the various chairmen have tried to summarize the results of the presentations and discussions. Let me hope that the engineers will soon know exactly how to design a column of optimum dimension in a building. Perhaps as suggested by Mr. Sfintesco you are so happy about this meeting that you may as well stay for a while in Paris and enjoy some other of its aspects. I thank everybody for coming, I thank Mr. Sfintesco, his staff and the secretaries for the organization. Thank you.

L.S. BEEDLE :

We certainly cannot leave without expressing our appreciation to our host Mr. Wahl and especially to Mr. Sfintesco, for someone who in August, this past August, had to pick up the challenge of organizing this meeting and holding it and conducting it in such fine style really deserves our thanks.