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Autor: Garas, F.K.

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The substance of our work is not only a verification of the structure of a nuclear vessel with finite element method - as it would seem to appear at first sight - but is infact an exact indication of the necessity and possibility of complementarity for those involved in the designing, verification of physical and numerical modelling, as well as for those who provide information on rheological behaviour of materials.

In our case the information obtained from the physical model suggested an investigation in the elastic linear field and has allowed an evaluation of the elastic modulus of concrete. The results of tests carried out on samples of concrete of the same type as that used in the physical model - elaborated with the matematical one - allowed evaluation of the elastic modulus by other means. The compatibility between the figures obtained through completely different methods was morethansatisfactory.

The determination of the optimum prestressing sequence of cables and of local safety factors, complete the picture of information available and confirm a "modus operandi" which must be considered fundamental for structures, such as nuclear vessels, whose safety must not be in doubt.

II - 4 Dr. F.K. GARAS

I must apologize for not giving the participants enough time to read my paper, but if you work for a commercial organization you will realize it is not always easy to find time to write papers. However, I will try in the next few minutes to highlight some of the key points mentioned in the paper. The paper deals mainly with the problem of high shear stresses which have to be accommodated in the design of prestressed concrete pressure vessels as shown in figure 1 of the paper. This shows a section through the Hartlepool/Heysham podded boiler type pressure vessel. There are four vessels of this design under construction at present in the U.K.

Pressure vessels for the containment of nuclear reactors include structural members which rely for their safety on the capacity of concrete to resist high shear stresses. Typical examples are end slabs, the barrel wall and boiler closures. These members are geometrically deep in relation to their span and subject to flexure, but the large deformations which would normally be induced are restricted by lateral restraint in the form of either prestressing or the continuity of the structure around the element considered. The first part of the paper is a summary of an experimental investigation into circular end slabs. Figure 7 in the paper shows the type of model which was used. To date we have tested 23 models to failure. They varied in scale between 1/24th and 1/8th scale. The parameters studied included the amount of hoop prestress, bonded reinforcement, span to depth ratio, boundary conditions, penetration liners, sustained temperature and concrete strength.

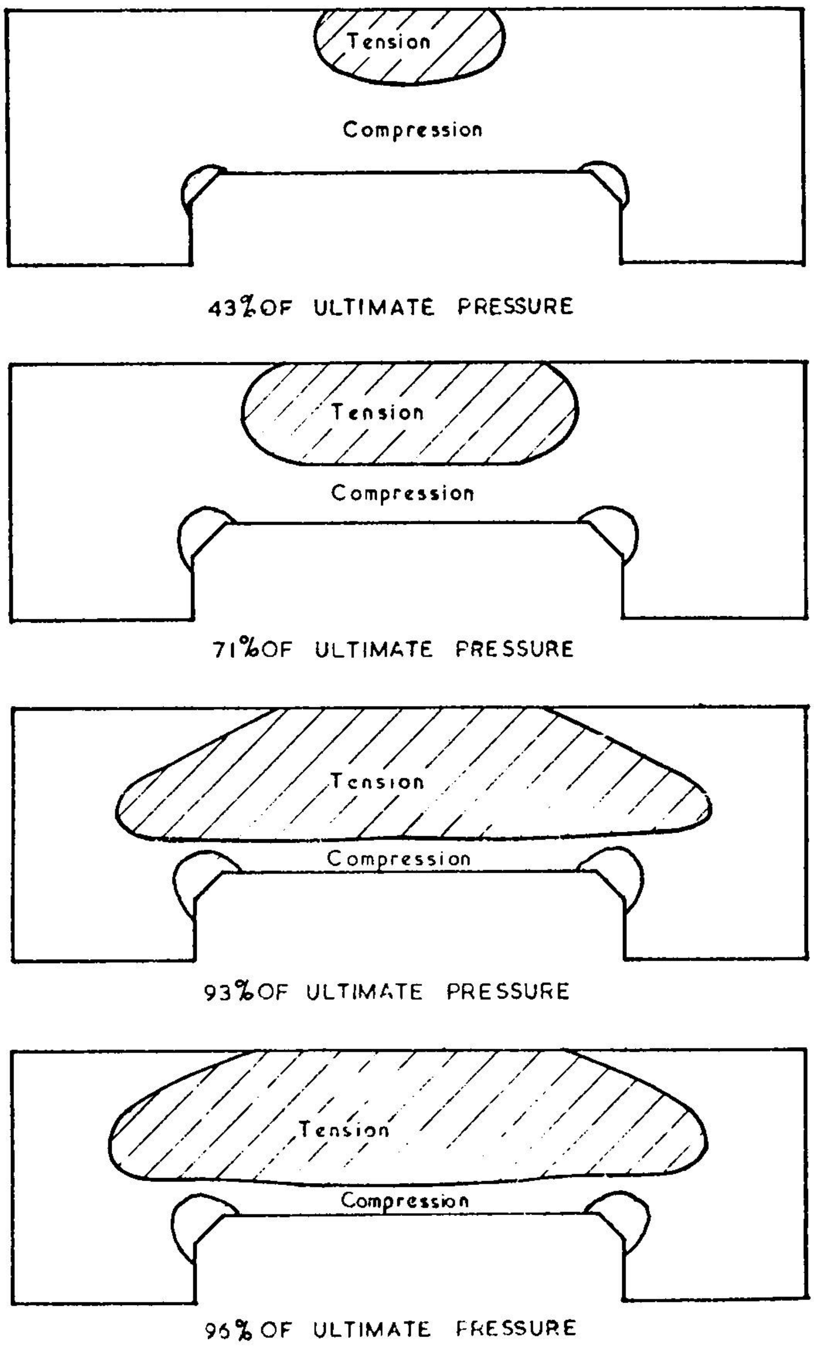
Figure 6 in the paper shows the general behaviour of a typical model. Here we plotted the percentage of ultimate pressure versus the percentage of maximum central deflection. The flexural behaviour can be divided into three stages. The first, the elastic stage, was determined by the pressure at which the first crack occurred, the next stage, elastoplastic, where boundary reinforcement started to yield and we got higher deflections and the last stage is the plastic stage. This behaviour was overcome by a shear type failure which is shown in Figure 7 in the paper. This is a typical failure in which a shear plug is formed with the exit of the plug determined by the position of the vertical prestress. The angle of shear plane was found to be determined by the span to depth ratio and the amount of hoop prestress.

In analysing the behaviour of end slabs we found that the ultimate shear strength was influenced by three components (figure 3 in the paper) - the compression zone, the small zone at the bottom, the aggregate interlock - which most people ignore in their analyses - and the third one, whose contribution is fairly small, the dowel action of the rebar.

In the end slab models a large number of internal and surface strain measurements were taken during the various stages of the tests and Slide 1 gives typical results.
The slide shows the development of the compressive and tensile zones as the pressure is increased. It can be seen that the reduction in depth of the compression zone can be determined from slab measurements. The first figure shows the stress distribution at 43% of the ultimate pressure. Although high tensile stresses of the order of 3000 microstrain were developed at the outer surface of the model it was still considered elastic. Figure 4 in the paper shows how the depth of the compression zone was reduced as the pressure was increased up to about 95% of the ultimate pressure. Prior to ultimate, the depth of the compression zone varied between 10 and 15% of the total depth depending on the type of model tested.

To give an idea of the breakdown of the total shear force between the three components previously mentioned, the compression zone represents about 45% of the total shear force, aggregate interlock as much as 50% and dowel action about 2 to 3%.

In the paper, an empirical expression is given which predicts the results of our experimental work and most of the published data. This is shown on page 5.



Development of Zones of Tensile Stress

SLIDE 1

The second part of the paper describes part of the development work carried out on the boiler closures for the Hartlepool and Heysham vessels. In each vessel there are 8 boiler pods, having a corresponding number of closures. Figure 2 in the paper shows the arrangement and various details. The paper describes the design philisophy behind these components.

To support the development of the design, models of 2 different scales were tested. Firstly 60 No. 1/10th scale models were tested and these were used to optimise on the design parameters and to examine their likely effects on the operational and overload behaviour. Figure 8 in the paper shows the test arrangement of the small scale models. The test programme is described in the paper. A typical mode of failure is shown in figure 10 in the paper. One of the significant results of the tests was the difference between the contribution of the active and passive restraint. This is one of the parameters which was examined and some of the models were tested with active and some with passive restraint. Figure 9 in the paper shows that the ultimate shear strength was 50% higher in the case of models with active prestress.

The results obtained from the 1/10th scale models were used in the final design of the closure but as a confirmatory measure 4 No. 1/3rd scale models were tested to examine the short and long term behaviour, using the test arrangement shown in figure 11 in the paper. The models were initially prestressed down and most of the components were scaled accurately. We used a hydrostatic pressure loading system. The test programme is described in Table 2 of the paper. M1 and M2 were tested in the short term at ambient temperature with passive and active prestress, respectively. In model M3, elevated temperature was sustained for a period of 9 months and M4 was temperature and load-cycled. Figure 15 shows a comparison between the measured and predicted hoop, creep strains for model M3 using a prediction based on Dr. Browne's work on the specific strain data for the Hartlepool concrete. Finally it is worth noting that generally there was good correlation between the behaviour of the two scales of model.