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# SUMMARY OF FATIGUE INVESTIGATIONS FOR SHIPBUILDING

by

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## 1. Introduction.

For shipbuilding it is of great interest to dispose of reliable information about the relative fatigue-strengths of structures made of Steel 42 and Steel 52.

The existing literature does not meet this need satisfactorily. Specimens and loads are often not sufficiently representative for ship structures. Also the criteria applied may differ from what is relevant. In ships cracks always start at weld defects at structural discontinuities. They may propagate to large lengths before becoming dangerous. This makes that generally information about the *propagation* stage of crack development is of more interest than information about numbers of cycles up to crack initiation.
Furthermore as even long cracks do not reduce the cross section of a ship substantially, they have little influence on the magnitude of the nominal stresses. Consequently results of constant-load tests will be too pessimistic for ships. Apart from that it is obvious that the loading of ships is not constant at all. This applies both to the amplitude of the loads as to the mean values.

Discussions between representatives of the Ship Research Centres and Laboratories of 5 European countries led to the conviction that primarily investigations with full size structural models were required in order to obtain direct indications about the fatiguestrengths of ship structures made of St. 42 and St. 52. However both fabrication and testing of these is expensive and time-consuming. Moreover only few laboratories are able to carry out such experiments.
Therefore next to a limited number of complex structures smaller and simpler structural models were designed to be tested at 100 tons-fatiguetesting machines. Finally unwelded notched plate specimens completed the range of test specimens. The three types mentioned form altogether a model family. They were provided with a number of strain gauges in order to be able to study correlations between the experimental results on the basis of significant (local) stresses.
*The correlations found are sufficiently accurate to allow the conclusion that predictions of the fatigue-performance of complicated structures are possible on the basis of results of experiments with simple models.*

This increases greatly the value of the results of the notched plate specimens.

The greater part of the investigation has been reported in /1/.
The Belgian experiments with continuous longitudinals (no interruption at transverse bulkhead subjected to bending) have been analyzed by ir. H.G. Scholte and reported in /2/.

The corresponding Italian experiments as originally conceived in the test program are also ready. The results were not satisfactory partly due to the small number of specimens and to differences between weld-details in the specimens. The Italian delegation has promised to let fabricate and test a number of new specimens for their own account. The testing has already started and the results will be made available to the European Community as soon as possible.

## 2. Discussion of program and results.

Figures 2-6 of the appendix show the specimens tested.

A summary of the conclusions from the experiments together with some final observations is given below.

*a. German experiments:* (crack-growth data not available).

1. In the region of relatively low numbers of cycles ($10^4$-$10^5$) there is a clear advantage for St. 52 over St. 42. This has been observed for both repeated and alternating loading. (Fig. 9).

2. A large influence of mean stress was found. At $10^5$ cycles alternating loading between +168 N/mm$^2$ and -168 N/mm$^2$ was aequivalent to repeated loading with a maximum stress value of 195 N/mm$^2$.
3. The importance of mean stress was confirmed in the experiments with program loading.
   A simple 3-stage program with large variations of mean stress resulted in markedly superior behaviour of St. 52 over St. 42.
   A multistage program with constant mean stress resulted in a much smaller advantage for St. 52.

*b. Belgian experiments.*

1. Conclusion a.1 of the German experiments is only slightly supported by the Belgian data. In fact only for axial alternating loading and bending repeated loading some advantage for St. 52 was found.
   It is of interest that the experiments for axial and bending repeated loading lead to the conclusion that the larger the crack lengths the more the results converge. This tendency was not observed for alternating loading. (Figs. 11 and 12).
2. Conclusion a.2 of the German experiments applies generally also to the Belgian data, but it became clear that mean stresses had mainly effect during the stage of *crack propagation*. For the stages of crack initiation no significant influence could be observed. (Figs. 11 and 12).
3. Between the values $c$ and $m$ in the formula

   $$\frac{da}{dn} = c\ (\Delta K)^m$$

   a unique relation was found for axial and bending repeated loading:

   $$c = 5{,}7\cdot 10^{-5} e^{-4{,}22\ m}.$$

   It applied as well to St. 42 as to St. 52 and to any of the three thicknesses 13, 19 and 25 mm.
   Alternating loading did not show the same relation. This may be attributed to closing of the cracks during the compressive part of the load cycles. This closing depends strongly on yield strength.
4. The fatigue-bending experiments with large size structural models resulted in a clear advantage for St. 52 over St. 42. (Fig. 8).

*c. French experiments.*

The results of the experiments with structural models in France, contrast sharply with those of the Belgian and German experiments with notched plates.

1. No advantage for St. 52 over St. 42 for both $P_{min}/P_{max} = -1$ and $-\frac{1}{2}$! (Fig. 23).
2. No influence of mean stress, not even for the larger crack lengths! The main explanation for the great differences in behaviour between welded structural and unwelded notched specimens may be that in the former residual stresses are present, which are higher the higher the yield point.

*d. Dutch experiments.*

1. Although not large, a distinct advantage for St. 52 appeared (10 à 15% at $10^4$ cycles), which became more pronounced the larger the crack length.
   It should be reminded that an advantage for St. 52 was not observed with the French experiments with *small* structural models. (Fig. 38).
2. The influence of test temperature was important.

*e. Italian experiments.* (See also introduction).

Comparing the results of the 4 specimens of St. 52 subjected to 3-step loading with the Belgian experiments for constant loading, no contradiction was found with conclusion a.3.

*f. Final observations.*

It is remarkable that some conclusions which have been drawn from the results of the simply notched specimens differ essentially from those for the welded structural specimens. Due to that, a straight-forward answer to the question whether higher strength steel behaves better or not than mild steel under cyclic loading is difficult to give.

The results of the German experiments with non-welded specimens show clear advantages for St. 52 over St. 42 in the region of higher stress amplitudes. This is not confirmed by the Belgian results. The large structures tested in Delft, Belgium and Italy support this tendency. Furthermore the non-constant load tests with widely differing programs (notched specimens) showed a superior behaviour for St. 52. However, the French results are in opposition. Taking all results together, the advantage for St. 52 is apparent. But obviously unknown factors may cause deviating results. A closer analysis of results, fracture areas, and physical properties of the fractured material, together with some additional testing may clarify the picture in the future.

An important part of the whole investigation has been the search for correlations between the results of structural and non-structural specimens. Many small strain gauges have been used in order to be able to present the data in terms of "nominal" or "local" stresses. A satisfactory correspondance was found between the results in terms of local stresses for the large and complicated structures tested in Delft and Belgium, and the smaller simplified structures tested in France.

Rather satisfactory correspondance was found between the results of on one hand structural and on the other hand notched plate specimens. For instance in figs. 47 and 49 the curves 2 for local stresses in the structural specimens ($P_{min}/P_{max} = -\frac{1}{2}$) fall between the curves $P_{min}/P_{max} = 0$ and $-1$ of the notched plate specimens.

A fracture-mechanics approach in the evaluation of the results proved to be satisfactory.
When a choice must be made between the results for $P_{min}/P_{max} = 0$ and $P_{min}/P_{max} = -1$, it seems wise to take for shipbuilding $P_{min}/P_{max} = 0$. An additional advantage is, that it is also the cheaper type.

Of great importance is the observed influence of mean stress on the fatigue results. This was the outcome both from the experiments with constant load amplitude and from the programmed load tests. In the latter especially the influence of the *variations* of the mean stress level became evident. It appeared that mild steel suffered much more from the influence of the variations of the mean stress level than higher strength steel.

References.

/1/ Nibbering, J.J.W., H.G. Scholte and J. van Lint, Synthesis of cooperative fatigue investigations with notched plates and welded ship structures of St. 42 and St. 52. Report NSS-TNO no. 206 S, Dec. 1974.

/2/ Scholte, H.G., Fatigue experiments with full-scale bottomlongitudinals of St. 42 and St. 52 under alternating bending. Report no. 195 S.S.L. Delft, March 1975.

/3/ Paetzold, H., Vergleichende Untersuchungen an gekerbten Proben aus Schiffbaustahl A und DH 36. Bericht 33/73, F.D.S. Hamburg.

/4/ Report 153/4585 of the "Lab. voor Weerstand van Materialen en Lastechniek", Rijksuniv. Ghent.
Report 153/4706 of the "Lab. voor Weerstand van Materialen en Lastechniek", Rijksuniv. Ghent.

/5/ Compte rendu d'essais de fatigue en traction ondulée et traction-compression d'éléments soudés. L'Armement Lopard. Paris 1973. Ministère d'état de la défense nationale; direction technique des constructions navales.

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# A P P E N D I X

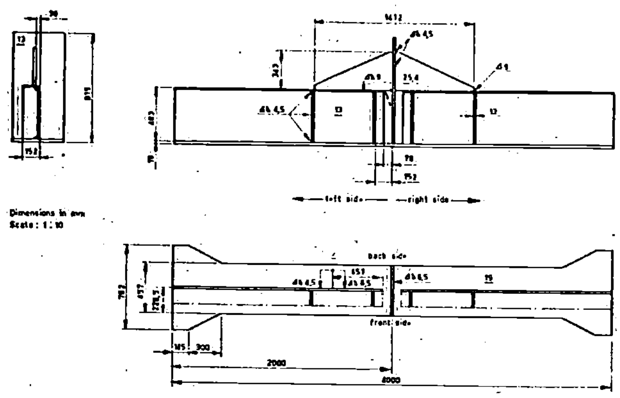


Fig. 2.
Large scale specimens
(Dutch experiments).

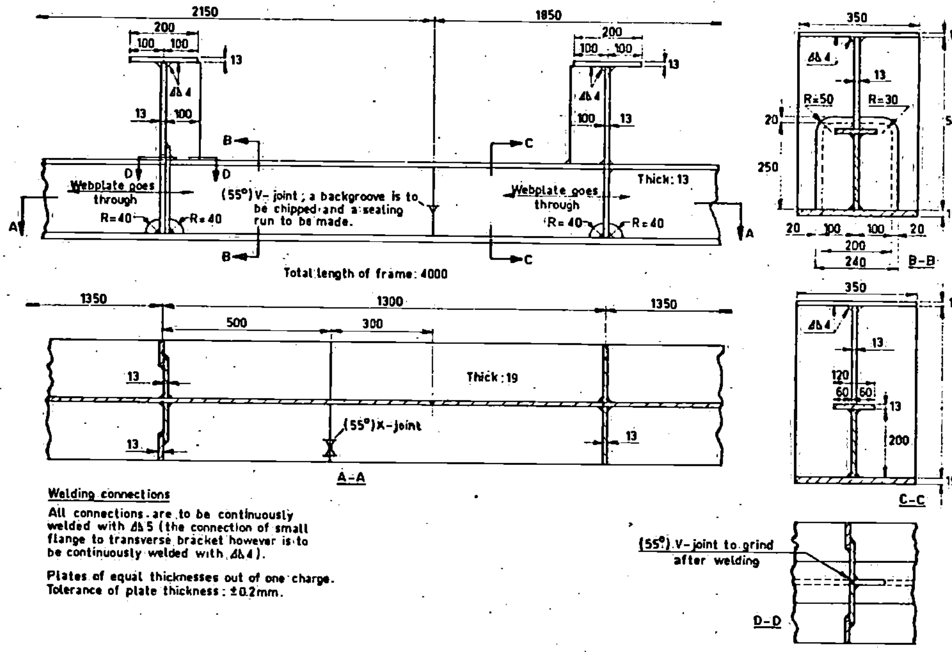


Fig. 3.
Large scale specimens
(Belgian and Italian experiments).

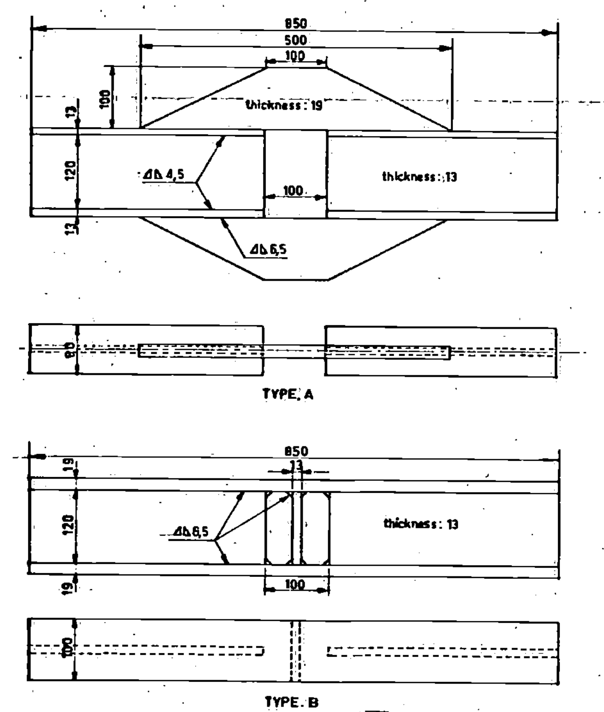


Fig. 4. Specimens type a and b (French experiments).

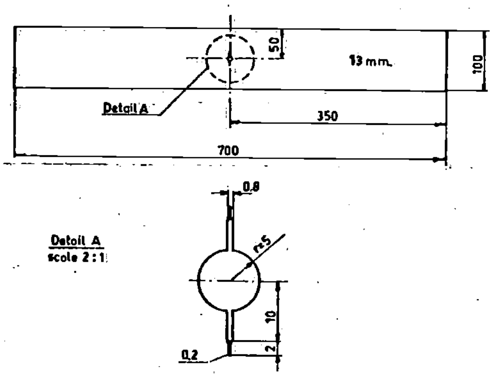


Fig. 5. Specimens (German experiments).

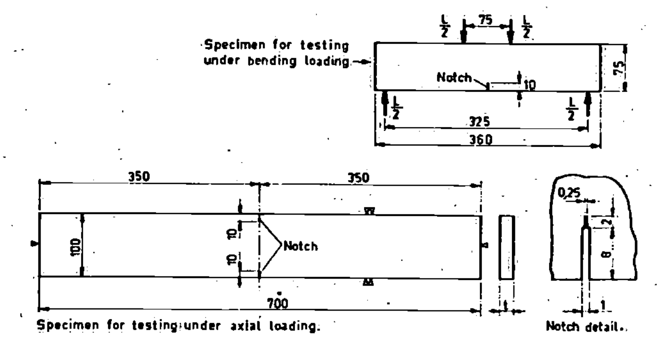


Fig. 6. Specimens (Belgian experiments).

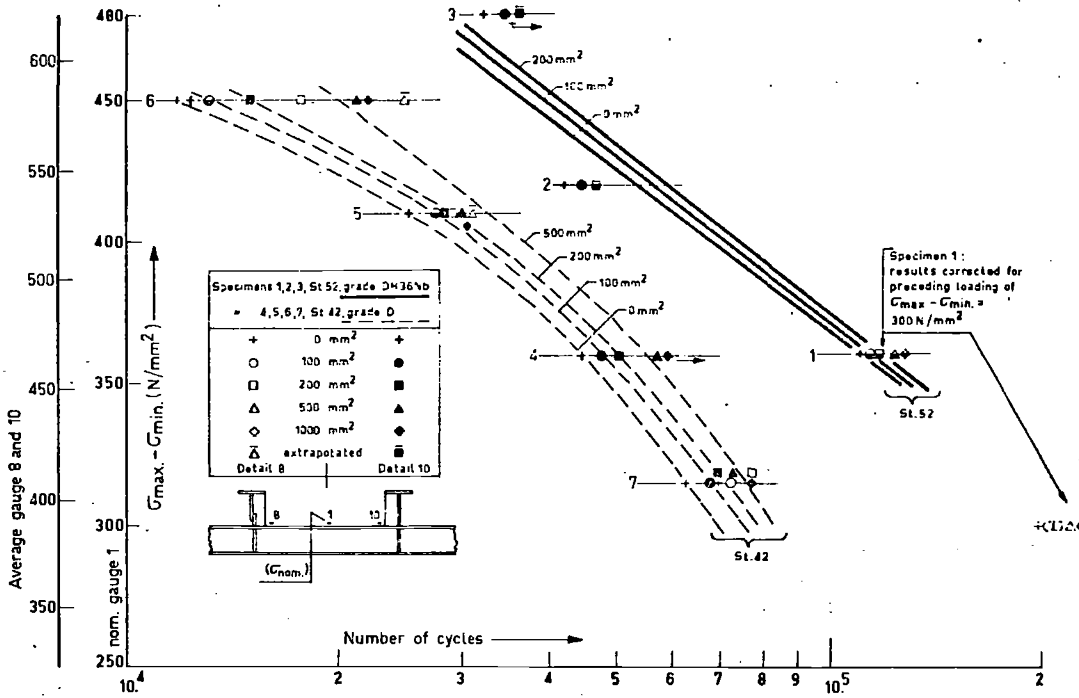


FIG.8 WÖHLER CURVES FOR VARIOUS CRACK AREAS OF BELGIAN LARGE SCALE SPECIMENS; St.52,grade DH36Nb. AND St.42,grade D. BENDING LOADING $\sigma_{min.}/\sigma_{max.} = -1/2$

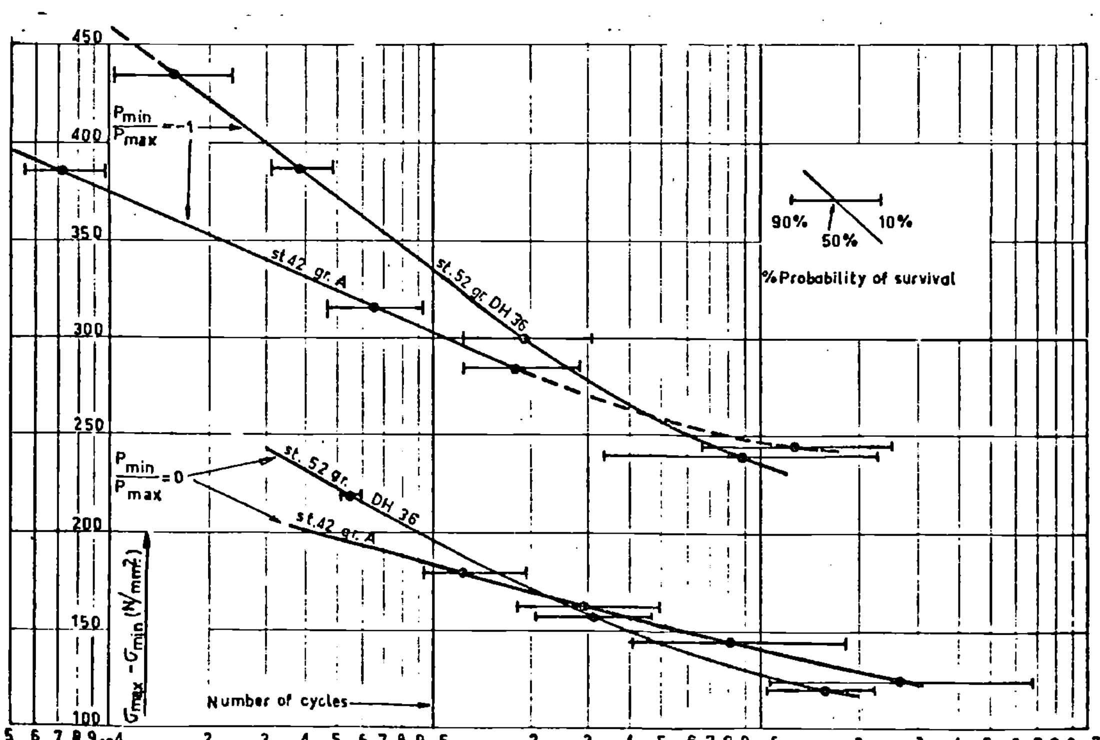


FIG.9 RESULTS OF GERMAN EXPERIMENTS WITH CENTRALLY NOTCHED PLATES UNDER AXIAL LOADING.

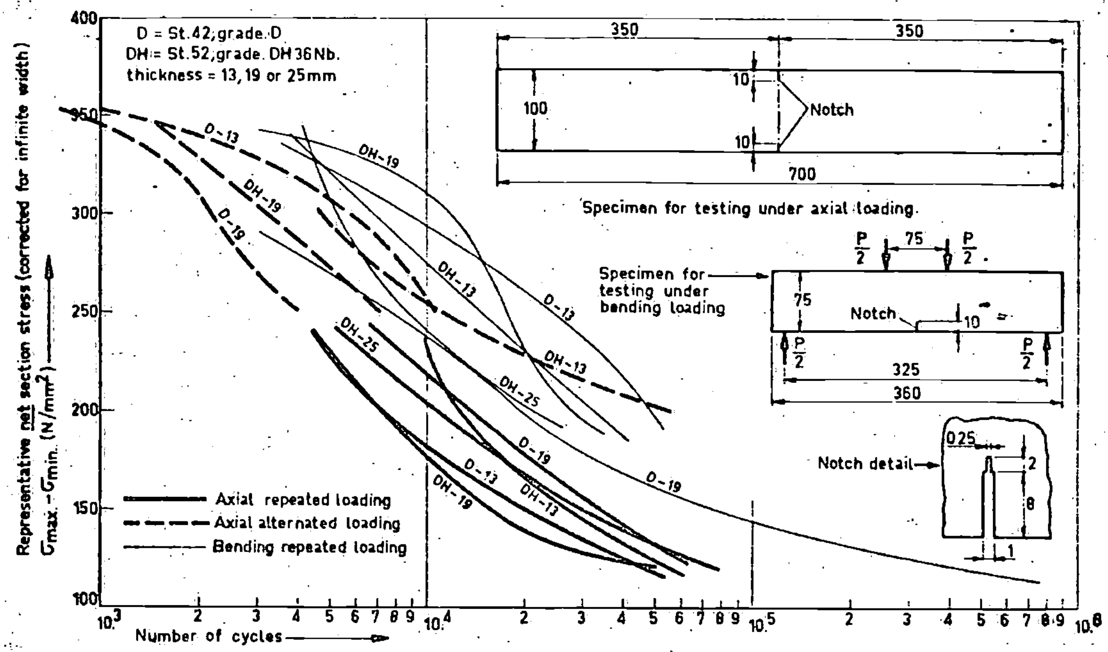


FIG. 11 WÖHLER CURVES FOR 1mm CRACK-LENGTH OF LARGEST CRACK (BELGIAN SPECIMENS).

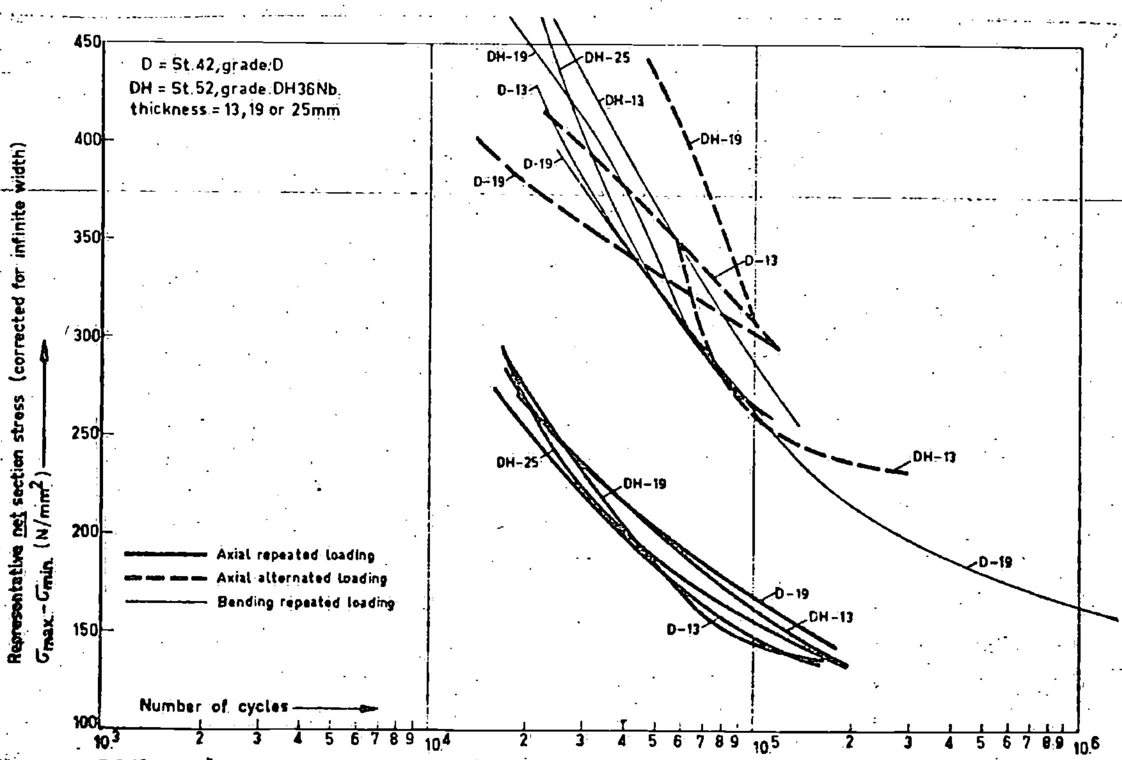


FIG. 12 WÖHLER CURVES FOR 20mm CRACK-LENGTH OF LARGEST CRACK (BELGIAN SPECIMENS).

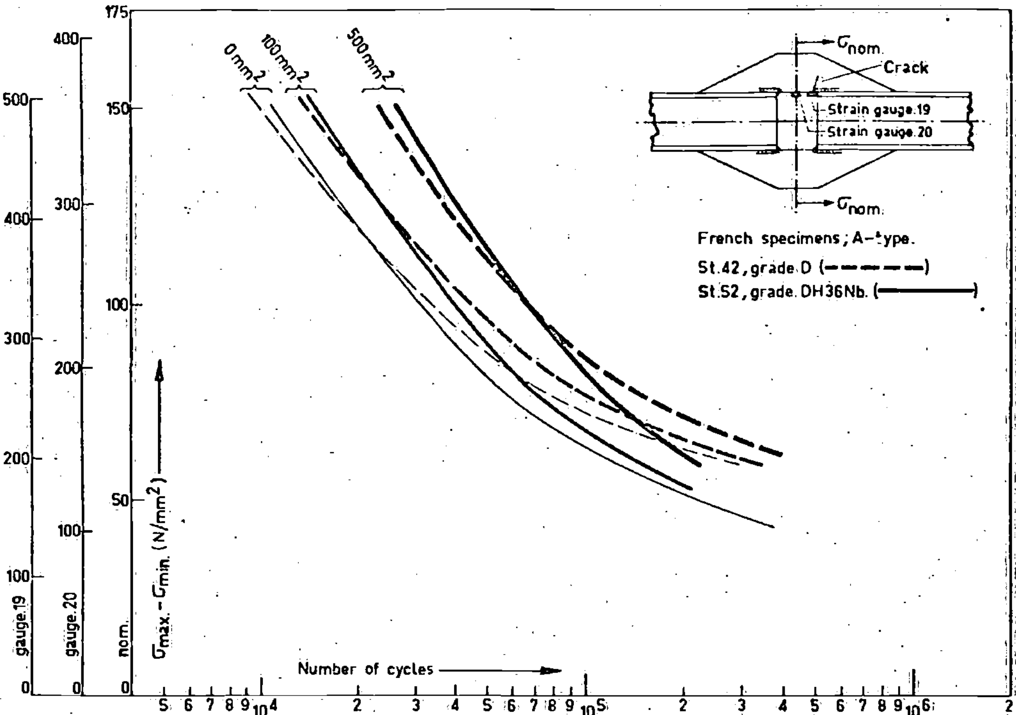


FIG.23 WÖHLER-CURVES FOR CRACK AREAS OF 0, 100 and 500 mm², A-type SPECIMENS; $P_{min}/P_{max} = -1/2$

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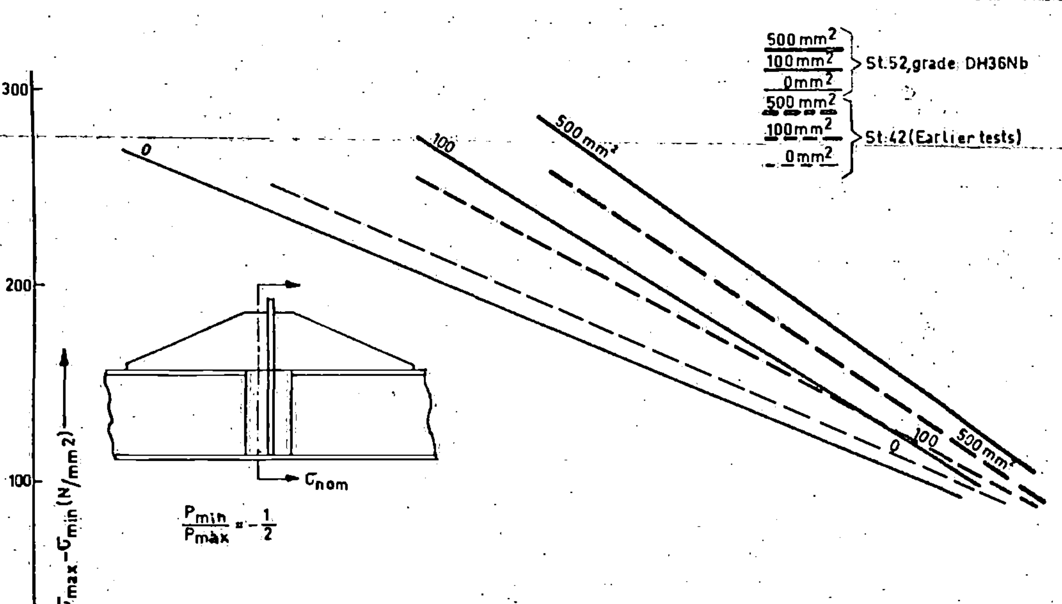


FIG.38 COMPARISON BETWEEN THE RESULTS FOR St.42 grade D AND St.52 grade DH36Nb BRACKETS – + 20°C.

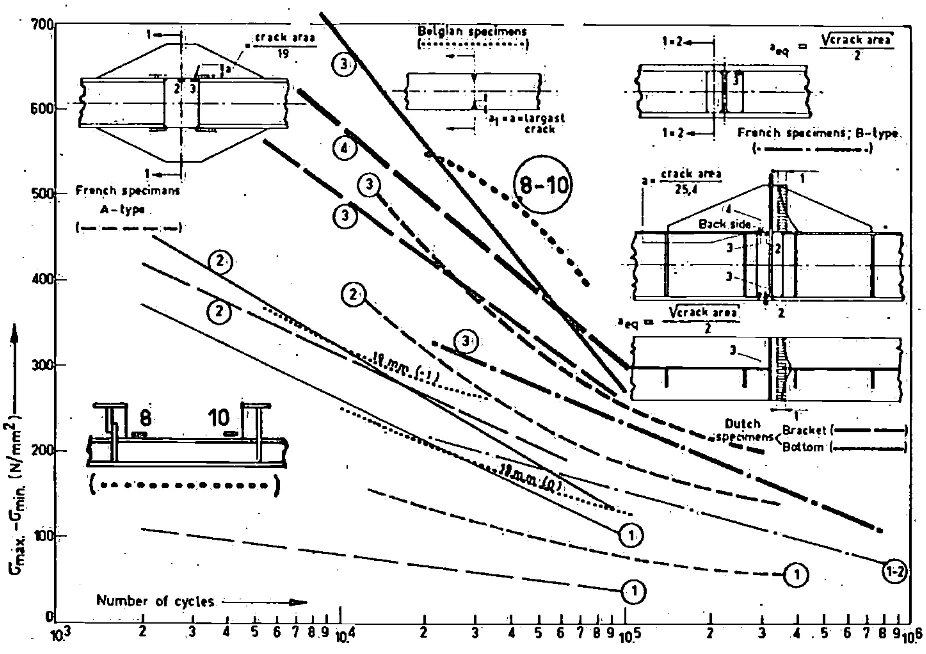


Fig. 47–49 Comparison of all results, now including the large scale specimens tested in Belgium for 5mm crack-length (a or $a_{eq}$)

Dutch-, French- and Belgian structural specimens: $P_{min.}/P_{max.} = -1/2$

Belgian notched bend specimens: $P_{min.}/P_{max.} = 0$ resp. $-1$

St. 42

St. 52