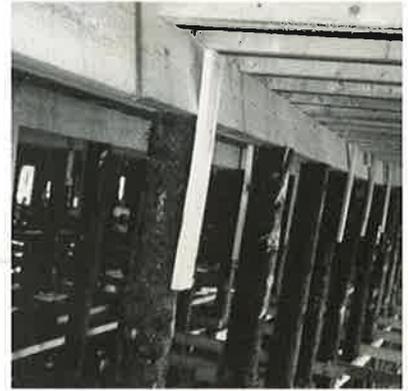


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ROYAL INSTITUTE OF TECHNOLOGY
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Construction Loads on Shores and Stability of Horizontal Formworks

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TRITA-BKN. Bullentin 35, 1997
ISSN 1103-4270
ISRN KTH/BKN/B--35--SE

Doctoral Thesis

This Thesis consists of two parts:

Part I

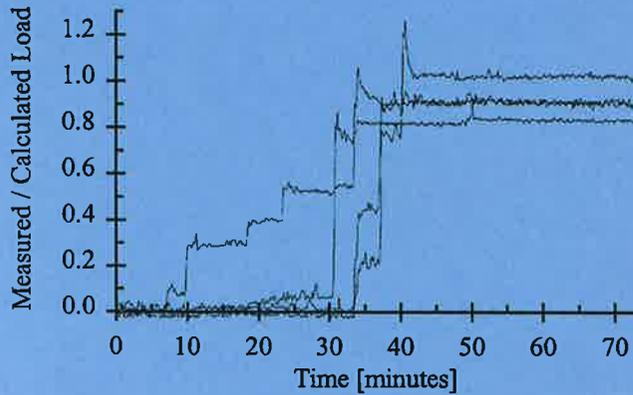
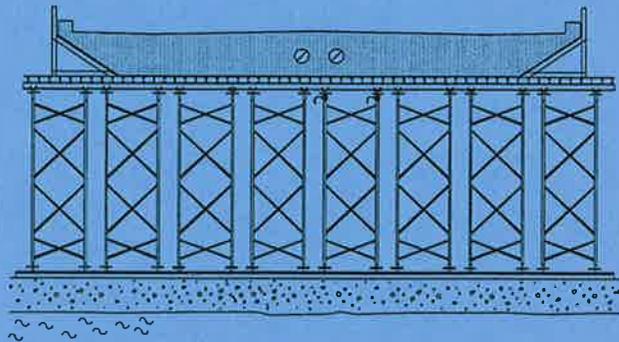
Construction Loads on Shores

Part II

Stability of Horizontal Formworks

Part I

Construction Loads on Shores



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6 Conclusions and suggestions for further research

6.1 Conclusions

Calculation of vertical loads on horizontal falsework constructions is based on self weights and variable loads. Self weights represent the loads due to concrete, reinforcement and formwork, and the variable loads represent the loads imposed by workmen, tools and implements, material stacks and dynamic load effects during concreting.

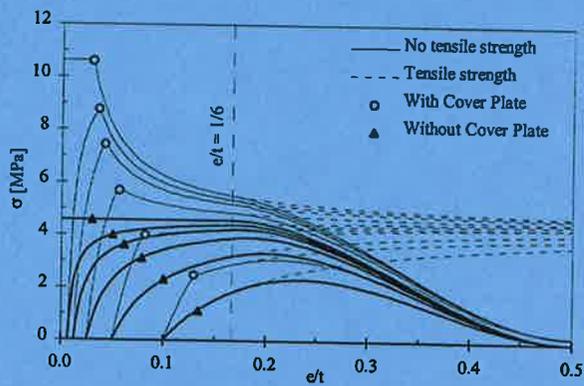
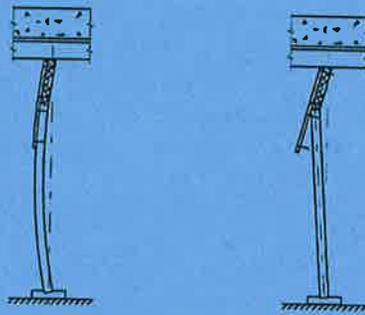
On the basis of the results of this thesis, the following conclusions can be drawn regarding the vertical load on horizontal falsework during concreting:

- When the concrete was pumped, the variable loads had no significant effect on shore loads.
- When concrete was delivered in skips, there were dynamic load effects in the form of short term increases in load between 5 and 30% when the skip was emptied. Part of this load increase was due to the dynamic effects of the falling concrete, and part to temporary accumulations of concrete. The magnitude of the increase in load is influenced to a high degree by the consistence of concrete, the thickness of the slab, reinforcement, the height of the skip above the formwork, rate of emptying, etc.
- Apart from the shores which were affected by dynamic loads when the slab was up to full height, the maximum shore loads occurred when concreting was finished and the variable loads were removed. This means that only self weights need be considered when shore loads are to be calculated.
- The relative shore loads, i.e. measured loads divided by calculated loads, had a relatively great variation between 0.15 and 1.5. This implies that it is the way in which the soffit formwork, joists and stringers distribute the load to the shores that is absolutely critical for the magnitudes of the relative shore loads.
- It is a common conclusion in previous works in which shore loads were measured that the large variations in relative shore loads are due to the initial load on the shores, i.e. the load due to soffit formwork and reinforcement. However, their conclusion could not be confirmed since in previous works the initial shore loads were not measured.
- The theoretical analysis which was carried out shows that when there is an initial gap between shore and stringer there are large variations in the relative shore loads, which should confirm the conclusions of the previous works referred to above.

- The author's own measurements showed however that large initial shore loads need not at all times be followed by large relative total loads, nor should the reverse necessarily occur. At some of the structures where measurements were made, some of the shores had the highest relative shore loads due to total load, in spite of the fact that they had had the lowest initial relative shore loads.
- One explanation for this may be that the components of the falsework straighten up from their initial deformed shape after a certain load has been applied. Another cause may be that one and the same components of the falsework may have different material properties. Some of the stringers may for instance have different material properties due to damage or differences in moisture ratio. Yet another cause may be that the load due to the reinforcement is in the form of point loads since the reinforcement is supported on chairs, which means that shores below the supports for the reinforcement may carry large initial relative loads. On the other hand, concrete which is a uniformly distributed load gives rise to more even distribution of the load.
- It was found that, due to the design practice applied at present in which load consists of self weights and a fixed value of the variable load, shore loads may in certain cases be underestimated when the slab is very thick.
- The mean value of the self weight of plain concrete came to 22.8 kN/m³. The corresponding mean for reinforced concrete was 23.2 kN/m³, i.e. somewhat lower than the value 24 kN/m³ which is common in design. On average, the weight of formwork and falsework, i.e. the weight of soffit formwork, joists and stringers was ca 2.5% of the weight of concrete, which is considerably lower than the commonly used value of 10%. Structures in which the soffit formwork consisted of precast floor units are not included in the above.
- The two methods of calculating shore loads, the beam method and the simplified method, were largely comparable. The beam method, however, gave a slightly better mean value of the relative shore load, but the standard deviation was somewhat larger than in the simplified method. The simplified method is thus highly satisfactory for the calculation of shore loads. Measurements by Fattal (1983) also showed that the two methods are of equal merit.
- A theoretical analysis of beams on flexible and rigid supports showed that, for a usual value of the relationship between the stiffness of the beam and the rigidity of the support, the simplified method gives results in better agreement with actual support reactions than the beam method. This may explain why the two methods were of equal merit in spite of the simplicity of the simplified method.
- In designing beams and calculating the support reactions for beams acted upon by point loads, point loads can in most cases be replaced by a uniformly distributed load.

Part II

Stability of Horizontal Formworks



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8 Conclusions and suggestions for further research

8.1 Conclusions

In designing traditional slab formwork, i.e. a horizontal soffit formwork carried on joists and stringers supported by vertical shores, it is usual for each part to be designed individually. The shores are designed with respect to buckling, the stringers and joists with respect to flexure and shear. A check is made on deformations etc.

This thesis has studied the resistance of a traditional slab formwork. The following conclusions have been drawn:

- In a traditional formwork, with the stringers laid on top of the shores, there is a risk that collapse will occur in 'knee buckling' unless the overturning of the stringers is prevented.
- In tests, timber stringers on shores in many cases failed at loads lower than those permitted according to the Swedish building regulations. This clearly shows that stringers on shores cannot be designed safely in isolation using the permissible values set out in codes, unless overturning of the stringers laid on top of the shores is prevented.
- When the stiffness of the stringer perpendicular to its longitudinal axis is lower than the axial stiffness of the shore, and overturning of the stringer over the top of the shore is not prevented, the resistance is in most cases lower than the buckling load for the shore. In some cases the resistance is only one tenth of the buckling load for the shore.
- Calculated ultimate stresses were in good agreement with those measured, and showed that knee buckling occurs when the stress at the joint face between shore and stringer and between stringer and joist has reached the end of the initial straight portion of the stress-strain curve for the material, i.e. the limit of proportionality, or has passed beyond this. The ultimate stress was thus between ca 1.0 and 1.2 times the limit of proportionality.
- If the stresses in the stringer come up to these levels, overturning of the stringer must be prevented or the contact stresses reduced by means of a packing of e.g. steel in order to spread the load over a larger area and thus reduce the stresses.
- When compressive stresses perpendicular to the grain in a timber stringer are high, i.e. situated on the flatter portion of the stress-strain curve, plastic hinges are formed at the

junction between stringer and shore and stringer and joist. Once these hinges have fully developed, the resistance of the shore-stringer construction is exhausted. In the case of towers with stringers laid on the top tubes which had been extended too far and have no horizontal restraint, calculations show that, when these hinges have developed, the resistance is substantially smaller than the buckling load according to Euler Case 1 for the unrestrained shore top, i.e. buckling of a column hinged at the bottom and free at the top.

- Calculations of the ultimate stress for shore-stringer constructions with a cover plate on one side showed that the cover plate greatly increases the resistance of initially straight constructions, but when the constructions have an initial eccentricity, the effect of the cover plate on resistance is dramatically reduced. When initial eccentricity is $e_0 = 0.05t$, a cover plate on one side increases resistance by only ca 25%. In reality, constructions cannot be counted on to be initially straight.
- Tests showed that when the stringer is attached to the shore by a cover plate on one side, the resistance is increased by ca 20%. Cover plates of the type that are commonly used do not prevent knee buckling. If this is to be achieved, a stiffer cover plate properly fixed to both shore and stringer must be used, or the tops of the shores must be laterally restrained to prevent horizontal displacement.

8.2 Further research

In this thesis, tests were confined to shores and stringers of timber and a thickness of 45 mm. It would be of great interest to study the resistance of constructions of other thicknesses and other materials.

Today it is very common to use shores of aluminium or steel. Stringers are usually prefabricated timber beams or aluminium sections with very thin webs. It would be of great interest to study the resistance of these, and particularly the resistance to torsion of the flanges of these aluminium sections in conjunction with knee buckling.

Stringers of aluminium sections often have slots in the flange for bolts which join them to the shore. A study should be made whether this prevents overturning of the stringer at high shore loads.