Full scale live load tests on a corrugated steel culvert

Full Scale Live Load Tests on a Corrugated Steel Culvert

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Summary

As a part of a research project concerning the behaviour of large diameter corrugated steel culverts under shallow soil cover, full scale tests on a 6.0 m span pipe arch profile have been performed. The tests have included studies in the service limit state as well as failure load tests.

The loading tests have shown that the height of cover significantly influences steel strains, culvert deflections and soil pressures. The influence of moving vehicles almost equals that of static loading but it should be noted that the tests were conducted at low speed.

Failure load tests were performed at cover depth of 0.75 m (12.5 % of the culvert span). Although some influence on the bearing capacity of simulated defects of the culvert could be noted the degree of compaction dominated the behaviour of steel culverts and therefore the load bearing capacity. Measured failure loads were quite high and shows that design methods in current bridge codes are conservative for culverts with shallow cover influenced by live loads.

1. Introduction

Corrugated steel culverts have been used in Sweden since the mid 50's. The spans have been moderate and the minimum and maximum heights of cover have been chosen with great caution. The corrugated culverts have in many cases proved to be economical alternatives to conventional concrete bridges. Therefore the interest in such structures has increased. This is especially true today considering the intensive expansion of the infrastructure and an increase in load carrying capacity of older Swedish bridges in order to conform with European standards.

The culvert used in this study was a pipearch profile with a span of 6.04 m and a rise of 4.55 m. The corrugation was a 200 × 55 mm profile with thickness 3.25 mm. Main dimensions, excavation pit size etcetera are shown in Figure 1.

The structural steel plates forming the culvert was bolted together using 15 bolts/m. Th. number of bolts was intended to give a seam stronger than the structural plate itself based on the ring compression method combined with classical buckling criteria.

Gravely sand was used for culvert bedding and backfilling. The compaction effort conforms to Swedish standards (four passes with à 450 kg vibrating plate using 0.30 m lifts). Compaction

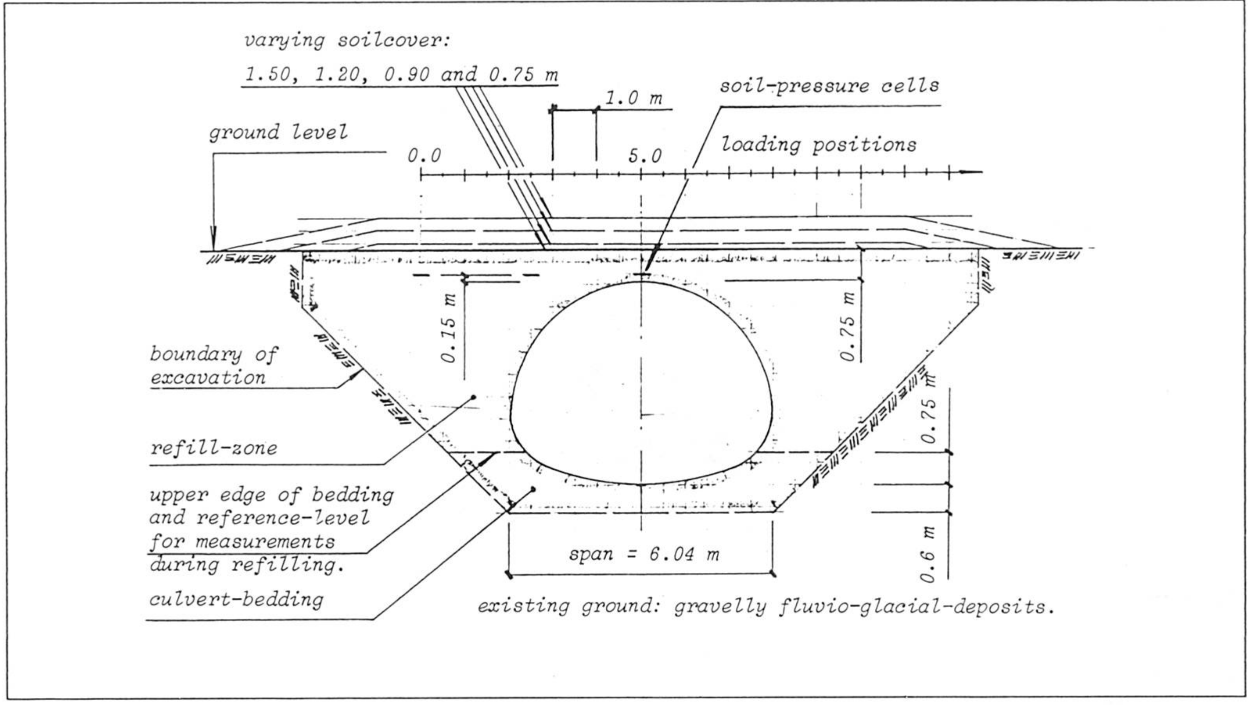

Fig. 1 Transverse section through test-culvert.

resulted in a mean dry density of 1.77 g/cm^3 giving a degree of compaction of 89% (modified Proctor). Also, plate pressure tests were performed at the level of the culvert crown. These tests, conducted according to the German DIN preliminary standard 18 134 gave an secant modulus (using pressures between 150 kPa and 350 kPa) of 56 MPa at the first load cycle and 107 MPa at a second load cycle.

2. Varying Height of Cover

The influence of the height of cover was the main objective of this study, since the soil cover is essential for the live load bearing capacity. Loading tests, statical as well as with a moving vehicle, were performed at successively reduced heights of cover of 1.50, 1.20, 0.90 and 0.75 m.

The loading tests were performed using a wheel loader with two axles and an ordinary lorry with three axles. The vehicles were moved over the culvert in 0.5 m steps. The configuration of the axles made it possible to study the influence of axle spacing, boggie loading compared to single axle loading, and the influence of increased load at given axle spacing. For each loading position soil pressures, steel strains and culvert deflections were recorded in three sections as shown in Figure 2. Note that the culvert is divided into three disconnected parts, reducing the end effects to a minimum. Some results from this investigation are shown in Figure 3.

Measured thrust of dead load only showed good agreement with the total weight of the super-imposed soil masses. However, there was a considerable redistribution of soil pressure measured directly under one wheel of the loading vehicle in loading positions 2.0, 3.5 and 5.0 (Figure 1) compared to free field measurements well away from the culvert.

It is well known that moving loads can cause increases in stresses compared to static load cases. Uneven surfaces and movements of the loading vehicle and the loaded structure can interact to

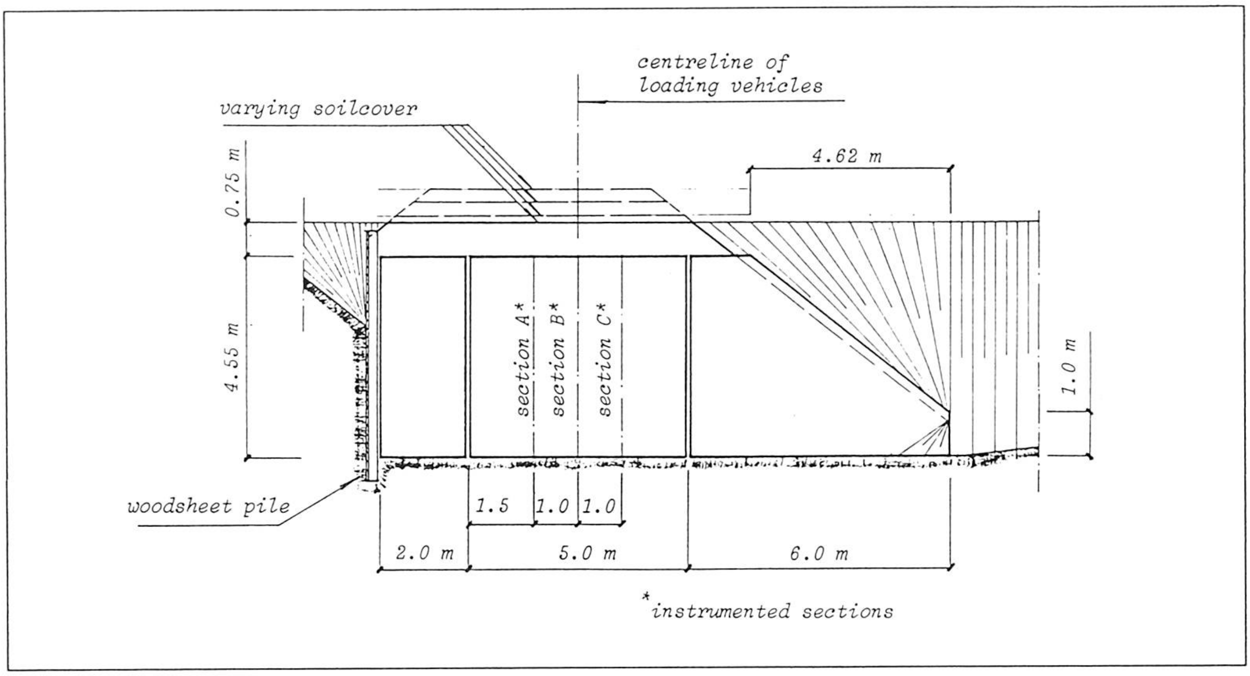

Fig. 2 Longitudinal section through test culvert showing instrumented sections.

cause considerable dynamic amplification of the stresses in the structure. It is believed that the impact factor is less for soil embedded structures than for conventional bridges. Some tests were therefore performed using a moving vehicle (wheel-loader at approximately 20 km/h) to compare the results with those from static loading tests. Some results are presented in Figure 4.

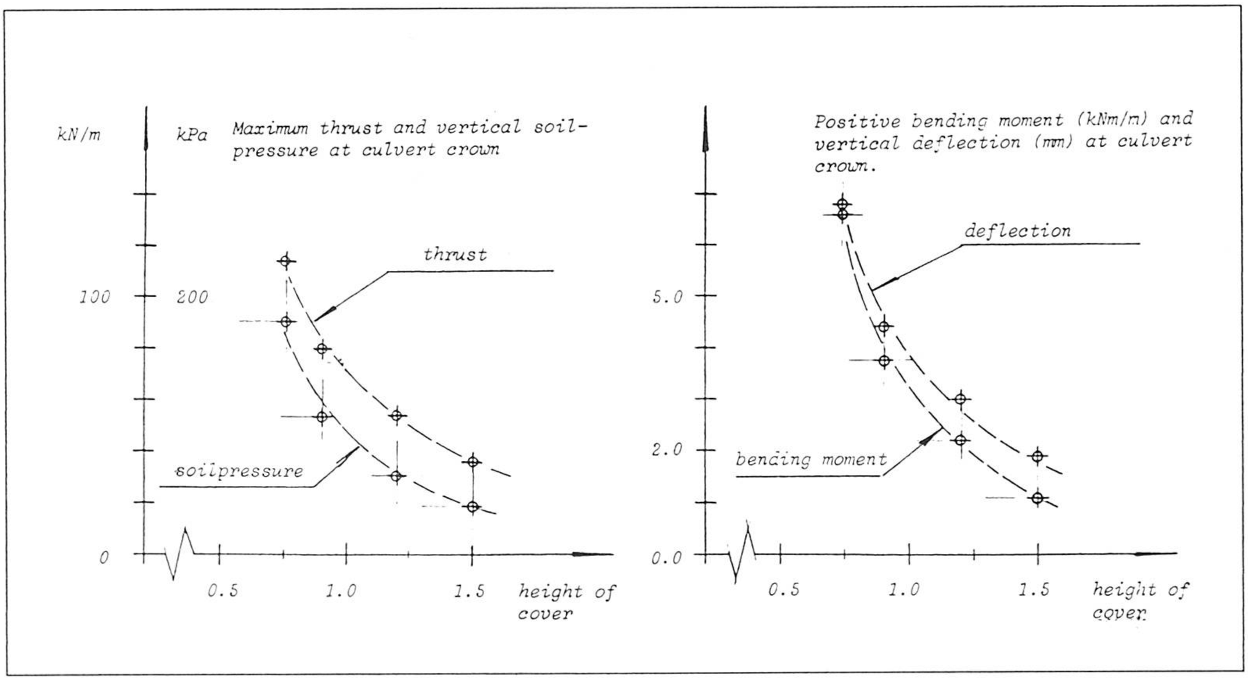

Fig 3. Thrust, bending moment, deflection and vertical soilpressure at culvert crown. Loading vehicle: 300 kN wheel loader with 225 kN on front axle.

3. Failure Load Tests

Knowledge of ultimate load behaviour is essential for the choice of safety factors for different kinds of structures. Because of the costs involved in full scale failure tests, there are very few such tests reported in literature. Due to the complex interaction between the culvert and the surrounding soil these tests are necessary in order to confirm theoretical studies. As a part of this full-scale test a series of five failure tests were performed all with a loading consisting of one axle. As failure tests lead to some parts of the structure being demolished (in this case the top plates) the culvert was uncovered and the top plates where exchanged after each test.

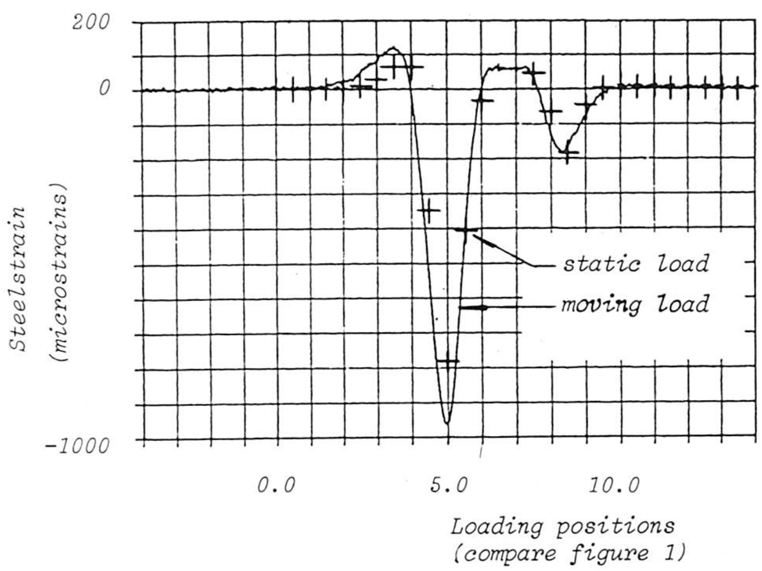

Fig. 4 Steel strains at culvert crown caused by a moving vehicle compared to steel strains caused by the same vehicle in static load positions.

The experimental program consisted of five independent failure load tests. The loading device is shown in Figure 5. It was designed to comply with the geometry of the live-load axle of the Swedish bridge code. The distance between the centre line of the two wheels is 2.0 m and the contact area of the wheels are 0.2 × 0.6 m. The load was applied using steel weights of 500 kg and 1000 kg respectively. All tests were performed at a height of cover of 0.75 m (12.5 % of culvert span).

At the first four tests, the load was applied directly over the crown of the culvert. In the last test the load was applied 1.0 m off the centre of the culvert (see Figure 5).

In the three first tests the degree of compaction (DOP) varied between very low values (approximately 80 % modified Proctor compaction) and high values (approximately 95 %).

Measurements showed that thrusts are almost independent of the DOP. However, moments and deflections increase with decreasing DOP which was expected. The vertical soil pressure over the crown of the culvert showed a linear increase with the load applied. When failure of the structure was encountered (a single wave buckle directly under one of the two "wheel loads") the soil failed in a manner similar to a punching failure.

At the last two tests, two rather usual defects on corrugated culverts were simulated in order to study their influences on the live load bearing capacity. A number of culverts have experienced slowly increasing deformations resulting in flattening of the culvert profile. The reasons being insufficient compaction of backfill material, poor quality of backfill material and poor quality of subground soils. These deformations also affect the moment distribution. Thrusts are probably not affected to any considerable extent.

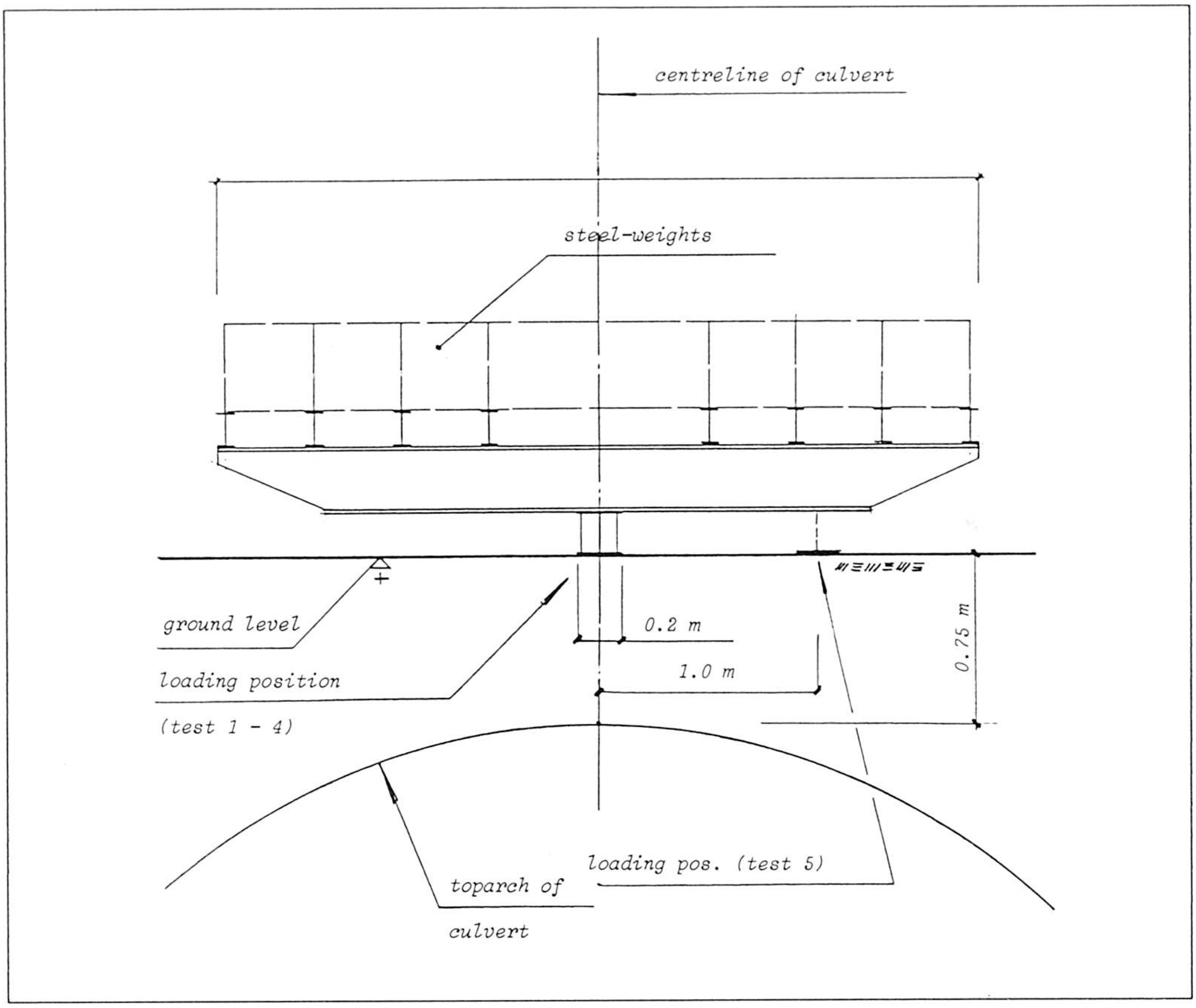

Fig. 5 Loading device for failure load tests.

The long term deformations were simulated by placing soil on top of the culvert before backfilling. The soil was kept in place by two "wings", in eleven and one o'clock positions as ca be seen in Figure 6. In this way a permanent vertical deformation of the profile of 0.18 m (3 % of culvert span) was achieved. After finished backfilling (the wings were removed during backfilling) the culvert was loaded to failure in the same manner as above. The failure load was reduced by approximately 15 % compared to the undeformed case. In this case yielding of the culvert wall started at the crown, initiated by positive bending moments.

Another encountered defect is local corrosion in the "splash zone" of water bearing culverts. This type of defect was simulated by cutting off small oval steel medallions, leaving a section approximately 2.3 m over the bottom of the culvert with only 10 % of the original steel area. Theoretical calculations showed that this reduction in wall section almost should cause yielding of the section from thrust only. The single axle was placed one meter away from the centreline

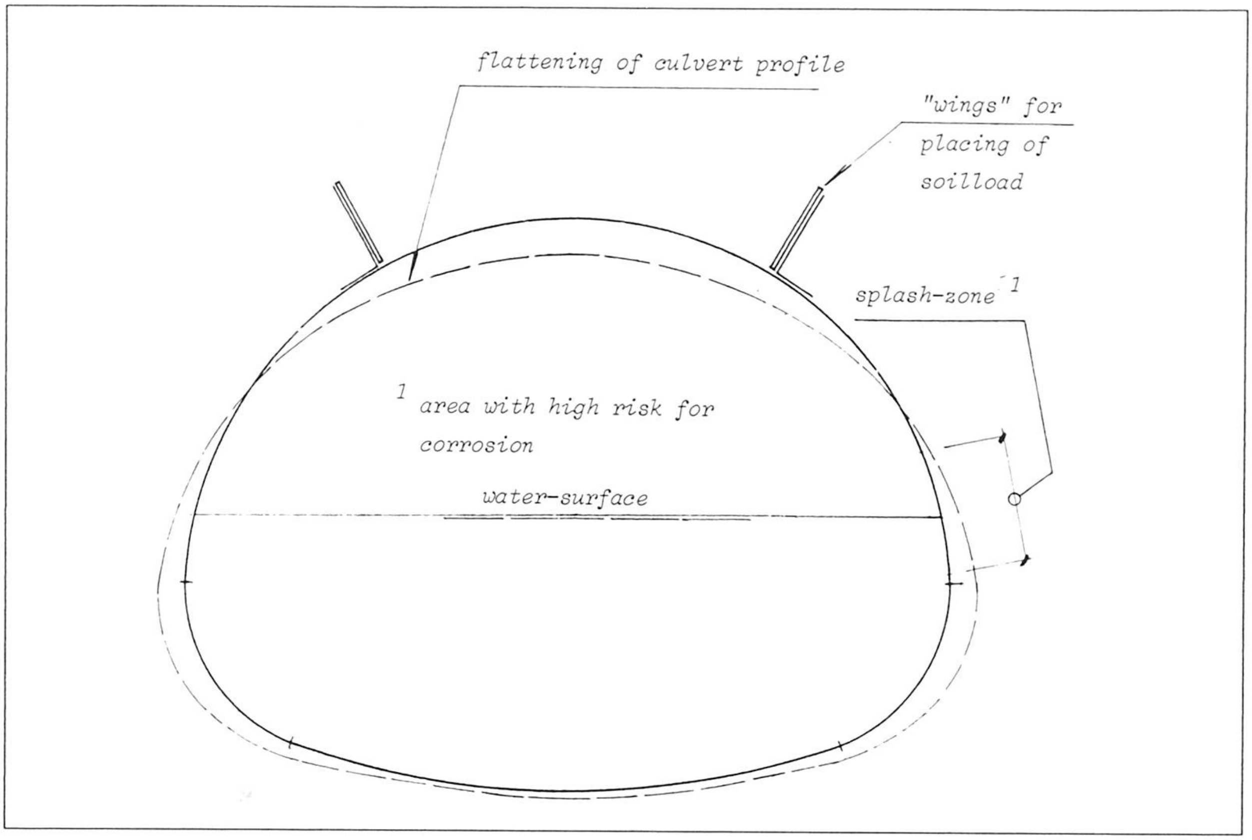

Figure 6: Typical defects of corrugated culverts (flattening of culvert profile and corroded splashzone).

of the culvert in order to attain maximum thrust in the weakened zone. The load was applied in the same manner as described above but the failure did not consist of a collapse of the "splash zone" but in a soilfailure with a sliding surface from the load towards the centre of the culvert (compare Figure 5). Checking of safety against soil failure must thus be included in an adequate culvert design.