Observations on the Collapse of the Scaffolding System for The Motorway Bridge at Exit 22, Nørresundby C

Wednesday, 24th April, 2006

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On Wednesday, 24 April, 2006, at approximately 10:00am, the eastern segment of a new replacement bridge crossing over the E45 motorway collapsed. The crossing is located approximately 1km north of the Limfjord tunnel at Aalborg. The bridge segment was under construction and wet concrete was being poured into temporary formwork. One person was killed and several injured.

This brief report constitutes a compilation of observations and comments following the authors' visit to the bridge collapse site several hours after the collapse and the following day.

General site observations

Initial observations were derived from the adjacent western segment of the bridge scaffolding, which remained standing following the collapse of the eastern segment. This was a consequence of the ongoing rescue efforts on the eastern segment and the assumption that the segments must have been very similar in construction philosophy.

Scaffolding, supporting the longitudinal I-beams that in turn supported the transverse I-beams spanning across the road, varied greatly in type, strength and stiffness. Inner scaffolding towers comprised different types of towers, including stacked tower segments, whilst outer supporting towers were lighter and of the common scaffolding systems used for direct support of concrete formwork. Sections of the yellow (perhaps old) crane segments were not always intact with large pieces of bracing often cut-out and not replaced. The variation in scaffolding types will have most likely created large variations in lateral and vertical beam support stiffness. Support foundations of the outermost scaffolds were weak, with direct connections of scaffolding through wood beams to the soil. None of the towers were restrained to ground.

The main longitudinal beams were supported on a system of temporary mechanical wedge-type jacks and smaller I-beams. Jacks were mainly arranged at 45° angles to the longitudinal beams, so that jacking bolts were neither parallel nor perpendicular to the longitudinal beams. The outer-most towers supported the longitudinal beams through a set of perpendicular I-beams, although configurations were not always identical. The inner towers were supported by a system of perpendicular I-beams and between two (2) and three (3) jacks. The assumption is that those towers supporting more loading had three (3) jacks, whilst those supporting less had two (2). The differing support conditions contributed to the varying support stiffness in both vertical and horizontal directions.

The positioning and number of jacks also raised questions about whether loading paths had been considered during the scaffolding design. Moment distributions along the supports would have removed any loading on the middle of three (3) jacks, whilst concrete pouring phase loads would have introduced moments at certain locations that may have only engaged one jack at a time. As such, if load bearing calculations had been made on the assumption that three (3) jacks would carry the full load, they would have been incorrect, as moment distributions would have only engaged one (1) or two (2) jacks at any one time.

The initial mounting of the longitudinal beams seems to have been done on two to three scaffolding towers each having two longitudinal and one transverse stacked small I-beam without use of jacks. These towers were of the common weaker scaffolding type for direct support of formwork. One of these towers seems to be placed at the edge of the formwork, thus possibly carrying a large load.

The lateral stability of the system seems to have been based solely on the capability of individual components to resist overturning moments, loss of friction and buckling instability. Stacked I-beam configurations had minimal lateral or rotational stiffness, both based solely on the beam webs. Additionally, total lateral and rotational stiffness was not the sum of each component, as components acted in series. This greatly reduced overall support stiffness. There was not visible additional lateral or planer stiffness - no bracing, cables, bolts, welds or other devices. This added to the impression that there was no residual robustness in the scaffolding system. The stability of the system seemed based solely on the stability of the individual scaffolding tower.

At some support locations (orange) restraining belts were placed through the bracing of the towers and around the longitudinal I-beam, thus jeopardizing the stability of the bracing and the tower. This was probably done to stabilise the longitudinal I-beam, whilst supported on the rather unstable jacks, until the transverse beams were placed on top. During the collapse the belts restrained the I-beams to a certain degree. It was noted that several of these belts were broken. The belts may also have provided a small but ineffective uplift restraint at some support locations, as restraining belts were tied between the tower and the longitudinal I-beam. However as mentioned the towers were not restrained to the ground.

In general, the scaffolding system seemed to lack robustness and most importantly redundancy. Every component was simply supported and stacked and any failure at any location could have lead to an overall failure of the system.

Once access was available, further observations were made on the collapsed segment. The support towers on the western side had all fallen outwards (to the west), whilst the picture on the eastern side is mixed and unclear. It seems that several of the northern-most towers on the eastern side collapsed outwards, whilst the southern most towers have collapsed inwards or towards the south. This may give an indication as to the source of the collapse mechanism.

The foundations on this segment seem fairly robust and unmoved, although measurement have not been taken to verify this. Access to the southern-most foundations on the eastern segment was not available.

Specific observations

Several supporting I-beam components seem to have suffered from uniform web buckling or web bending, which may be pre-collapse attributable. Supporting I-beams on the standing bridge segment were often eccentrically placed, in relation to the centre of the supporting towers, indicating that similar eccentricities may have existed along the collapsed segment.

Jacks used to support the longitudinal I-beams do not seem to provide a large degree of fixity in any direction with changes in load. Geometrical redistributions of the jacks with varying loads seem likely. Several jacks were found to be broken through brittle failure. This seems unusual considering their steel volume and stiffness. Only older type jacks were found to be broken. Male components on the segmental scaffolding were found to be rusted and weak.

Prestressing tendons were placed in the formwork before the concrete was poured adding load to the system. This is not suggested as common practice.

The western longitudinal beam of the collapsed segment was found to have been “flipped” by 90° clockwise facing north, so that the bottom of the beam was facing west and the top was facing east. This was determined by the jack and crossbeam rust mark patterns on beam. Parts of the eastern longitudinal beam were missing. Lateral-torsional buckling (kipning) of the longitudinal I-beam may have been part of the collapse mechanism. The lateral support offered by the jacks may have been very weak due to lifting of the outer parts of the I-beam.

Concrete cracking patterns on the “New Jersey” type crash barriers may help indicate the collapse mechanism. Cracking patterns seem to suggest that the eastern side may have fallen slightly before the western.

Note on collapse mechanism

There are some indications that the collapse started in the eastern midsection, quickly progressing to other parts of the segment. The location coincided with that at which rescuers worked to free the deceased construction worker. The indications include the amount and type of damage caused to the structural elements in the vicinity, the collapse patterns of the towers and surrounding scaffolding and the concentration of the concrete, although this is most likely due to differences in post elevation and pockets created by rescue attempts. Lateral movement of the central crossbeams and positioning of the longitudinal I-beams may also support this.