A discussion on the collapse of four curtain beams on the Ellis Brown Viaduct – 23 June 2012

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Durban's Ellis Brown Viaduct, crossing the mouth of the Umgeni River north of Durban, was in the spotlight last year, due to the detachment of four adjacent sea-facing spandrel panels collapsing into the river below. On examining the structural engineering sufficiency of the bridge, the role that structural engineers play in the development of permanent infrastructure was highlighted once again, with particular reference to their aesthetic contribution or lack of it.

INTRODUCTION

The Ellis Brown Viaduct is approximately 450 m in length, comprising 15 simply-supported spans of dual carriageway to carry the M4 (North) across the estuary of the Umgeni River.

Despite its appearance as a multiple-arch bridge, structurally this is not the case. The arches are façades on the sides of a typical beam-and-slab type deck and their structural purpose is to support a narrow (1.5 m wide) sidewalk. Since its construction in the mid-50s, there has been an on-and-off debate about whether the aesthetic appearance of multiple arches was the correct form to have chosen. Some feel that the openness of a light, slender superstructure is more appropriate for a wide estuary such as this (Figure 9 gives an insight into what appearance the bridge may have taken without the addition of the arches). Regardless of these opinions, the arched form, whether appropriate or not, has become iconic of Durban's beach-front.

The recent collapse of four of these façade beams re-ignited this debate (refer to the commentary at the end of this article) and forms the basis of this article.

SYNOPSIS

On the early morning of Saturday 23 June 2012, four curtain beams on the east (sea-facing) side of the Ellis Brown Viaduct over the Umgeni River at Blue Lagoon, Durban, became disconnected from the main structure and collapsed into the river.

The curtain beams are not an integral part of the main roadway structure, so the decision was made to isolate the now unprotected edge of the bridge with temporary precast concrete barriers and re-open the freeway to vehicular traffic. Pedestrian traffic will be

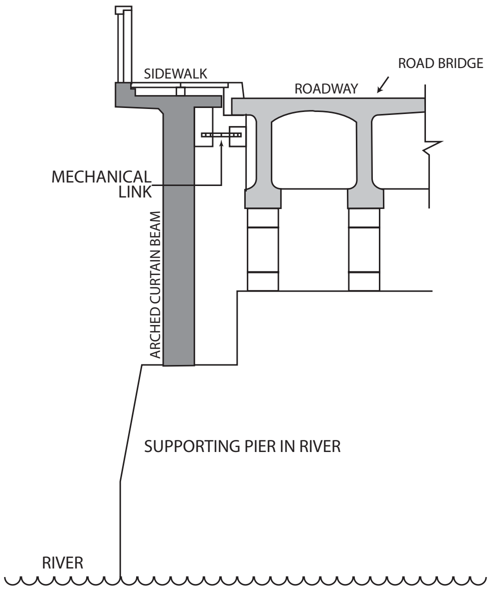

Figure 1a: Existing structural system

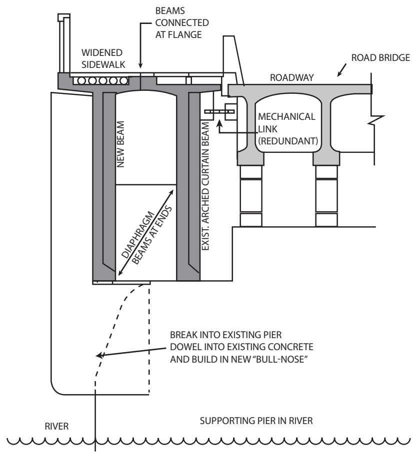

Figure 1b: Widened sidewalk as done on the western edge of the bridge

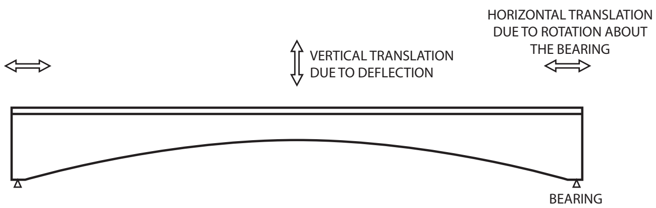

Figure 1c: Direction of freedom for hinges

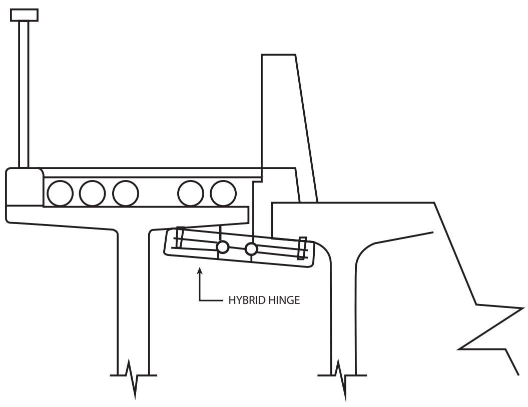

Figure 1d: A hybrid of the Mesnager Hinge is being considered

Figure 2: Hacksaw left on side of road bridge

limited to the newly constructed cycle lane / walkway on the west side of the bridge until the east side is fully reinstated.

This discussion encompasses the reason for the collapse and a few of the solutions being considered.

EXISTING STRUCTURAL SYSTEM

The existing structural system of the bridge consists of a pre-stressed concrete beam-and-slab composite deck supporting the roadway with an arched concrete curtain beam façade on the outer edges that forms the sidewalk and parapet. These beams are not connected rigidly to the main structure, but are held in the lateral direction with a series of mechanical links at seven points along each beam (Figures 1a and 8).

In certain places it was noticed during maintenance inspections that some of the links had begun to corrode, and a replacement programme using stainless steel was carried out as part of programmed bridge maintenance on several of the beams.

The recently constructed new cycle lane / widened walkway on the west edge of the bridge consists of an additional matching set of arched façade beams resting on an extension of the piers and have been rigidly connected to the existing curtain beams along the top flange, as well as at the ends with a concrete diaphragm, thus effectively making the structure self-stable and no longer reliant on the linking system to the main roadway bridge (Figure 1b).

CAUSE OF FAILURE

Clearly, vandalism for scrap had resulted in the removal of a number of the original links, as well as the newly replaced links throughout the structure (see Figures 2 to 5 for evidence of such).

The four beams along the mid-section of the bridge are over a section of a built-up sand 'island' at the river mouth which makes access without detection a little easier than other portions of the bridge. Notwithstanding, the links are still very difficult to gain access to and are some five metres above the river. It is here that the vandals were able to work methodically at removing almost all of the links, effectively rendering those beams un-propped in the lateral direction and potentially unstable. It is assumed that one of the beams toppled as a result of sufficient traffic vibration from the roadway bridge and dragged the potentially unstable adjacent beams along with it.

The remaining eleven beams on the sides of the collapsed section are being considered as potentially unstable, so a temporary additional measure of ensuring stability has been installed.

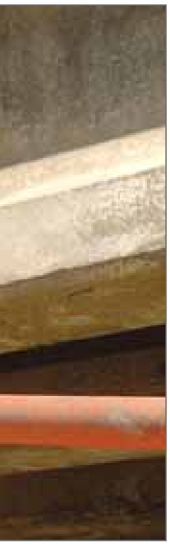

Figure 3: Freshly cut link showing hacksaw blade marks

Figure 4: Removed washer placed on top of diaphragm

SOLUTIONS UNDER CONSIDERATION

The ideal solution would be to widen the sidewalk with an additional set of matching beams on the outside edge, as done along the western side of the bridge. This alters the structural system to one which is stable, independent of the main structure. The 'arched' sidewalk beams adjacent to one another and fixed to each other along the top flange, and braced at the ends with diaphragm beams form an upside-down 'U' beam. The metallic links causing the sensitivity of the structure to vandalism and corrosion are thus rendered redundant.

Of course this 'widened sidewalk' solution has the added benefit of augmenting the non-motorised transport link across the Umgeni River, which is proving to be popular. Early indications are that the sidewalk on the western side, shared with cyclists, is going to be inadequate fairly early, as enthusiasm for that route to Riverside and the Bird Park is quite high. The paving would also match the other side with a neat in-situ concrete finish, as well as a light 'open' pedestrian handrail system of polymer concrete. Vehicular protection for the pedestrians would be in the form of a solid kerb-line barrier.

Despite the advantages of removing the dependency of the curtain beams on the mechanical links, the limitation of this solution is obviously the high cost (around R20 million).

The other alternative is therefore to only replace the four collapsed curtain beams.

If this minimalistic solution is adopted, then the solid kerb-line barrier, in-situ concrete paving and hand-railing system to match the newly revamped western edge of the bridge would still have to be included for pedestrian safety and for protection of services within the sidewalk. This cost is estimated at about R8 million.

The obvious challenge of the minimal approach is that the curtain beam façade will still depend on the main roadway structure for its stability. This challenge will include the necessity for a replacement linkage system to ensure lateral stability to the curtain beams that does not offer itself as an easy target for scrap vandals.

A few options are under consideration, the exact details of which are probably best not divulged, as they all have their weaknesses to vandalism. The basic theme of these options is based on a traditional reinforced concrete hinge, or Mesnager Hinge (named after the French engineer). These hinges, however, are usually utilised in (and depend on) highly compressed zones as part of a bearing or thrust of an arch. They are also limited to rotation in one direction only. The situation we are dealing with requires a hinge that must act in tension and allow translation in the vertical direction at mid-span of the beams and in a horizontal direction at the ends of the beams (Figure 1c). The horizontal movement required at the ends is as a result of rotation about the bearing, along with the normally expected longitudinal movements due to creep, shrinkage and thermal effects.

Currently, a hybrid of the Mesnager idea is being considered. Without revealing too much information about its weaknesses to vandalism, the idea is to cast a 'double-jointed' link in a polymer concrete encasement that could be fixed to the soffit of the

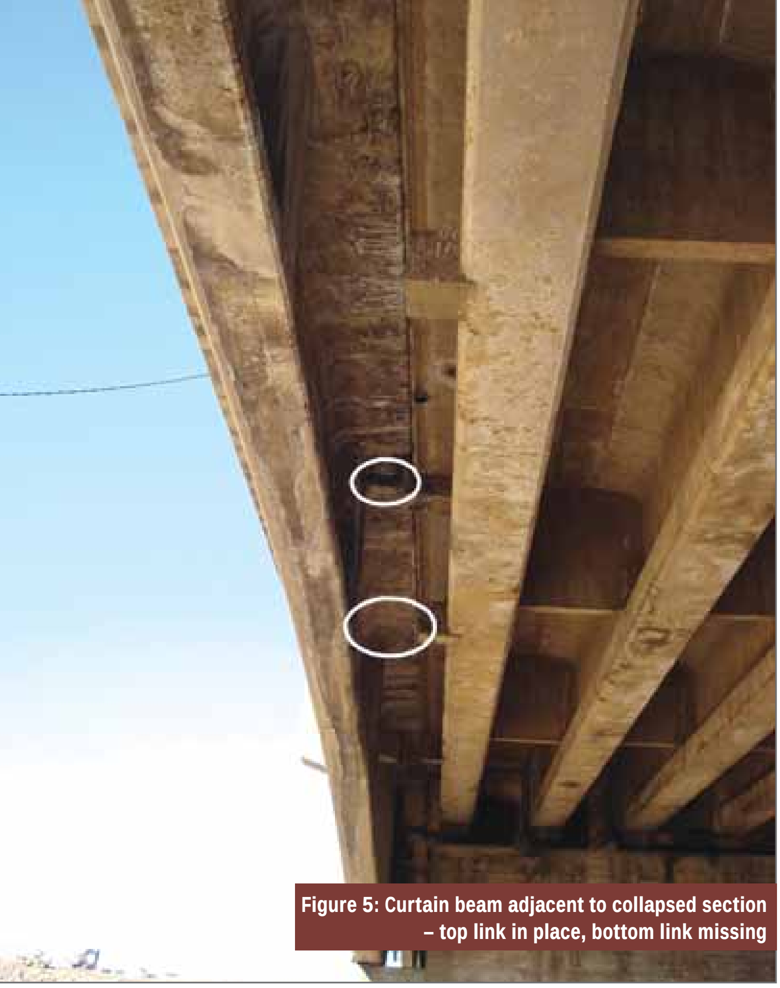

Figure 5: Curtain beam adjacent to collapsed section – top link in place, bottom link missing

bridge deck and curtain beam flanges, allowing the connection to simultaneously operate in tension, as well as vertical and horizontal translation (Figure 1d).

CONCLUSION

As implied by Prof Fleming (see comments at the end of this article), "if it looks right, it will fly right". The form of a structure should mimic the 'flow' of the stresses exerted upon it and not be something that it is not meant to be.

In this instance, the curtain beams are not acting as true arches; they are simply supported beams shaped like arches to make up a façade. They could not be rigidly fixed to the main roadway bridge deck because of their vastly different stiffness characteristics compared to the internal beam/slab configuration. The solution was to 'tack' them to the side of the main bridge in a day and age when scrap vandalism was unheard of. Herein lies the weakness of the system and the lesson of trying to force a structure to be something that it should not be.

EXPERT COMMENTARY

Professor Colin Fleming (past professor, University of KwaZulu-Natal):
The failure that occurred on Saturday 23 June 2012 cannot be called a failure of the structure; it is a failure of human beings to

Figure 6: Collapsed beams, looking south

Figure 7: Remains of a stainless steel replacement link

Figure 8: Typical example of one of the original links

Figure 9: This view of the collapsed beams from the south-east gives a hint of the slender 'open' form that the bridge may have taken if not given the false arched appearance

take note of a classic statement by a great engineering philosopher, Professor Hardy Cross, who said: "Structures are cleverer than we are: they will do what they want to."

The failure of the façades – for that is what they essentially are – on the Ellis Brown Viaduct (EBV) is a classic example of what should NOT be perpetrated: trying to show a structure as something different from what it is. A properly designed structure should stand in its own right. The great Italian engineer/architect, Nervi (a rare, successful combination of the two professions in one person!), said that if a structure *looked* right, it generally *was* right.

The history of the EBV has to be examined. The municipal powers-that-be were married to the idea of a so-called multiple 'arch' bridge with a profile of the type which eventuated. The truth is that the site was not in the least bit suitable for an arch of any type, single or multiple, so this was a misnomer from the outset, but the tender process ensued with the required profile. The successful tenderers were the worldwide firm, Christiani and Nielsen (C&N) who were pioneers in pre-stressed concrete, and proposed a largely precast solution of uniform depth beams at a great cost saving compared to any other method of construction.

The tender found favour, but the thought of the non-arch profile did not! The answer was the compromise which was a structural lie and the cause of the present problem: to attach the much deeper, heavier and costlier façades to the more logical and effective precast beams, which function correctly in carrying the roadway, while the façade 'arches' carry the sidewalk. Incidentally, the cost of each of the 'arches' was equal to the cost of five of C&N's beams!

Now to emphasise the main point of issue: the solution to the problem of erecting a multi-span bridge at the mouth of the Umgeni River as proposed by C&N was undoubtedly correct. Sixteen beams were needed per span, subsequently reduced to 14 to allow for the 'cosmetic arch' on each side, thus a total of 210 over the 15 (?) spans of the bridge and these were cast on the river bank. These could surely have been incorporated into a slender *honest* profile with probably more appeal (openness, etc) than the more cumbersome one which has endured and given rise to the present cost of correction, let alone initial expenditure.

Why did all this happen? It is the result of imposing on a good engineering decision a mixed solution to satisfy individual preference for an incorrect non-engineering theme. "Structures are cleverer than we are." Do not try to dictate to them what shouldn't be. One might fault engineers for accepting a compromise, but work pressures are overbearing!

Ivor Daniel (architect in private practice, Daniel & Associates Architects):
Design integrity, from an architectural perspective, incorporates functionality with aesthetic appropriateness within an overall

context. The appropriateness referred to is defined by application of context with the need for functionality of purpose.

In respect to bridge design, the functional requirement is to span a particular distance with the simplest of form and minimal material. This expression of function should therefore be incorporated in an holistic design solution. In the best of bridge designs, this symbiosis usually results in iconic design solutions. These bridges give particular meaning within their context (Golden Gate, Sydney Harbour, etc). To add superficial elements to the fundamental design requirements, in order to achieve pre-determined or desired aesthetics, takes away from the fundamental bridge design and therefore adds nothing of value in terms of its integrity.

The add-on components to the Ellis Brown Viaduct, by the above definition, add nothing to the overall integrity of the bridge design and are therefore 'design superfluous'. Their design intent appears to create an overall illusion of an arched span bridge. The simple form of the existing flat-span design has an honest functional requirement. The required pedestrian additions should therefore have been addressed as independent components with their own integrity rather than trying to change the nature of the original bridge design.

Rob Young (structural engineer in private practice, Young & Satharia):
On examining the structural engineering sufficiency of Durban's Ellis Brown Viaduct, after the detachment of four adjacent sea-facing spandrel panels and their collapse into the river below, the role that structural engineering plays in the development of permanent infrastructure was highlighted again, with particular reference to the aesthetic contribution, or lack of it.

In essence this bridge is a 'dishonest' structure. The elevation indicates a series of closed arches, whereas in reality they are false façade spandrel panels, disguising simply-supported precast pre-stressed beams.

The original design would have been based on an historic mass gravity arch concept – established long before the advent of modern structural engineering theory. Presumably this gave comfort to the more conservative Durban ratepayers at the time.

The impracticality of the originally proposed concept was displayed in the actual construction method proposed by the contractor. This provided the potential for a horizontal slim band of beams across the opening. The potential of visually opening up the natural banking of the river mouth and environment, still existing on the north embankment, was lost and the false arches stayed.

The immediately upstream Athlone Bridge crossing, initially a light-steel truss structure and now replaced by long-span cantilever pre-stress concrete beams, are honest structures, which open up the estuary.

The collapse of the false spandrel panels, without compromising the structural integrity of the remaining bridge structure, is possibly sending a message that structural engineering indeed provides honest and sustainable solutions in establishing infrastructure. ◻

Source: http://www.saice.org.za/downloads/monthly_publications/2013/2013-Civil-Engineering-March/#/0