Steel Impact and Fire Behaviour in Overheight Vehicular Bridge Accidents

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***Abstract*— After bridge fire events, the main task of engineers would be opening the bridge to traffic as quickly as possible without compromising the structural integrity of the bridge or the safety of road users. The recently published AS 5100.8 provides some guidance for assessment of bridge materials including steel, concrete, masonry and timber. However, the type and extent of required tests depend on the results of the preliminary inspection by specialist engineers and asset owners' strategic decisions considering the criticality of a bridge on the roads network. Therefore, there is a need for an efficient design of testing in order to ensure that the materials properties have not been jeopardised due to the fire within the limited allocated time-frame of bridge traffic closure. This task becomes more complex in cases that the vehicular impact causes a fire as steel losses about half of its strength when the temperature rises to almost half of the melting temperature.**

This paper presents a case study for assessment of possible changes in critical materials properties in the fire event on a bridge. Also, the paper highlights the need for a comprehensive guideline to bridge fire damage assessment and repair, depending upon the bridges' traffic functionality. This in turn may result in improving the bridge design strategies from fire safety perspective.

Keywords—materials inspection and testing, steel bridge, post fire assessment

I. Introduction

A study of bridge fire damage incidents in United States showed, even though fire damage is rare it is not so uncommon either. The majority of the fire incidents were caused by fuel tanker truck accident. In most cases the bridge did not collapse and only in few cases major structural collapse occurred or the bridge had to be demolished. However, in all cases high costs were sustained due to traffic closure [1]. Another study conducted in the National Cooperative Highway Research Program (NCHRP) and sponsored by the American Association of State Highway and Transportation Officials identified a strong correlation between that the risk of bridge fire and the likelihood of vehicle accidents on or under the bridge. The research compared steel's thermal and mechanical properties changes in high temperatures according to American Society of Civil Engineers and Eurocode prediction models [2]. There are also several studies on fire performance of specific bridge designs. Quiel, Yokoyama, Mueller, Bregman and Marjanishvili studied the effect of fire on a cable-stayed bridge [3]. On the other hand, Braxtan, Whitney, Wang and Koch investigated composite steel box girder bridges in fire and compared weathering steel and structural steel performance. They identified that fire beneath a box girder bridge poses a significant risk to the structural integrity [4]. This paper also presents a case study of in situ steel failure analysis. The paper describes the results of a materials investigation and tests as part of the assessment team, feeding to the asset owner for strategic decisions on the serviceability of the subject bridge. The bridge is located south of Sydney, NSW, Australia. The fire took place when a truck crashed into a safety barrier and was hanging over the side of bridge. Shortly after the crash, the truck was burning until the Rural Fire Service extinguished the fire. The crash closed a major arterial highway in both directions for several hours. A visual inspection of the bridge condition was quickly carried out by a specialist team of engineers from Roads and Maritime Services which was followed by detailed structural assessment and materials testing. As a result, the bridge could be safely open to traffic as early as possible.

Also, the paper highlights the need for a comprehensive guideline to bridge fire damage assessment and repair, depending upon the bridges' traffic functionality. This in turn may result in improving the bridge design strategies from fire safety perspective.

II. Australian standards Provisions

AS 5100.1 has left fire requirements to the discretion of relevant authorities [5]. AS 5100.2 includes a new fire effect load case in the 2017 revision, but it would still be subjected to the relevant authorities' specifications [6]. Similarly, parts 5 and 6 of the Standard provide some guidelines for structural performance of concrete and steel bridges respectively [7, 8]. They further refer to AS 3600 and AS 4100 for, if deemed necessary [9, 10]. AS 4100 and AS 3600 require fire resistance period for structural adequacy which is not mandatory in bridge design. However, the scenario of World Trade Centre towers proved that it does not cater for extreme cases. Perhaps, the building designers never envisaged impacts from fully laden (and fueled) passenger aircrafts. These buildings were steel framed not reinforced concrete as is more common in Australia. Although the aircraft impacts damaged a number of perimeter steel columns, there was sufficient redundancy to sustain the structure. However, steel columns require fire protection and this is normally achieved using a sprayed coating of Vermiculite and gypsum plaster. The fires raged for several hours before the towers eventually collapsed. This suggests that the fire proofing spray was of insufficient thickness to protect the columns for the duration of the fires that occurred.

III. CASE STUDY

A B-double truck crashed into a bridge in southern region of NSW, Australia. It was hanging over the side of the bridge after hitting the traffic barrier and igniting into flames. Fig. 1 is a photo taken by Australian Broadcasting Corporation (ABC) from the incident [11].

Fig. 1. ABC News phot from the truck crash and fire incident, south of Sydney, NSW [11].

The incident closed an arterial highway for a few hours until bridge engineers successfully completed their assessment. The bridge is a composite structure including steel box girders with concrete deck. This paper only focuses on materials testing of fire affected areas. However, this would be the first step in a post fire assessment which must be supplemented with system testing including speed limit, load rate, composite action, member distortion, bearing and expansion joints, welded and bolted connections as well as serviceability assessment of structure. Moreover, these are to be followed by developing any required repair technique.

Initially inside and outside of the steel box girder as well as concrete deck surface were visually inspected. Then non-destructive testing (NDT) was undertaken on both steel and concrete. NDT included magnetic particle and dye penetrant testing on steel and Schmidt Hammer testing on concrete. Then further detailed assessment of the steel was carried out by in-situ hardness testing and metallographic replication.

NDT did not indicate existence of any cracks in the box girder's steel plate or loss of surface hardness in deck's concrete. Also, in-situ hardness test results on the girder's heat affected areas were converted to equivalent tensile strength using AS 5016 2004 [12] and ASTM E140 [13]. The results indicated that the heat from the fire on and under the bridge had not adversely affected the mechanical properties of steel. This was also verified by microstructure analysis of the steel. The experiments were designed according to the suggested tests in AS 5100.8 [14] by Roads and Maritime Specialist Engineer and were successfully undertaken at the bridge site. The asset owner thanked and acknowledged the team for their prompt and dedicated teamwork in opening the bridge to traffic as quickly as possible without compromising integrity of the bridge or safety of the road users.

IV. DISCUSSION

Historically, fire damage assessment had not considered as a core expertise in Roads and Traffic Authority [15]. However, currently Roads and Maritime has material specialists in steel, concrete and timber who contribute in development and maintenance of bridge related standards too.

The recently developed AS 5100.8 provides general guidance for fire damage assessment as part of strengthening and rehabilitation of steel, concrete, masonry and timber bridges [14]. On the other hand, AS 5100.7 [16] which covers bridge assessment only requires assessment in a fire event without elaborating on the assessment methodology.

Assessing mechanical properties of a bridge element which is subjected to fire requires comparison of the fire event with the specific time-temperature curve. AS 5100.2 provides different approaches for determination of the curve as part of design for fire which could also be adopted for assessment, if deemed acceptable, including [16]:

- Specification of the relevant authority
- Replication of the fire
- Fire modelling
- Taking AS 1530.4 curves (Fig.2) [17]

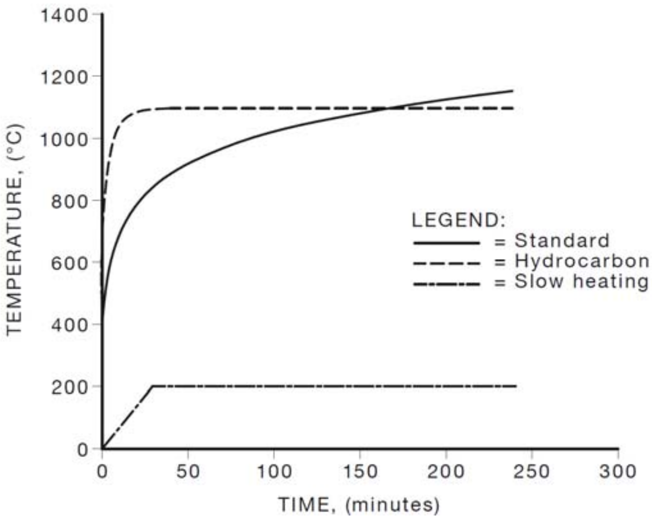

Fig. 2. Time-temperature curves for cellulose materials [17].

- Table 26 of the Standard (Fig.3).

Traffic type	Structural elements	
	Hydrocarbon fire curve	**Duration minutes**
Road	RWS/HCinc	120
Rail	RABT-ZTV	
Bus	RABT-ZTV	

Fig. 3. Design time-temperature curves for fire [16].

In addition, AS 4100 provides variation of mechanical properties of steel with temperature for determination of limiting steel temperature (Fig. 4).

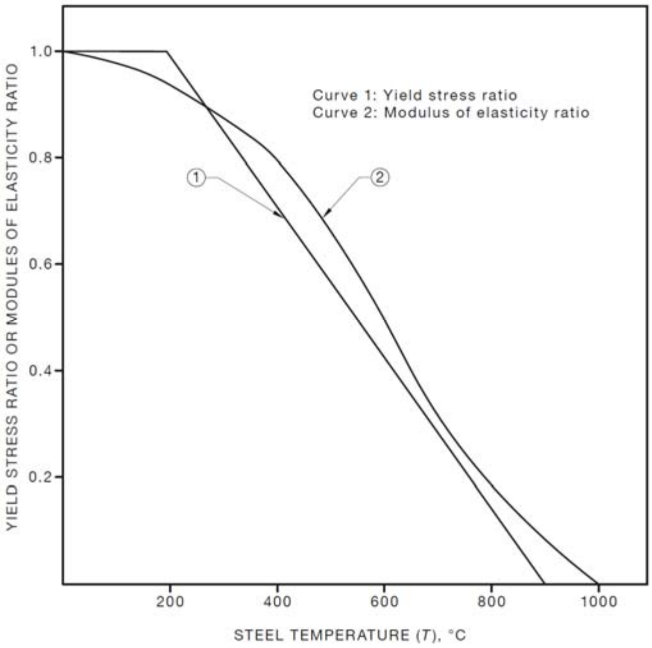

Fig. 4. Variations of mechanical properties of steel with temperature.

Furthermore, comparing the available data in Australia with international fire modelling practices [18] suggests determination of time temperature-curves comes with uncertainties.

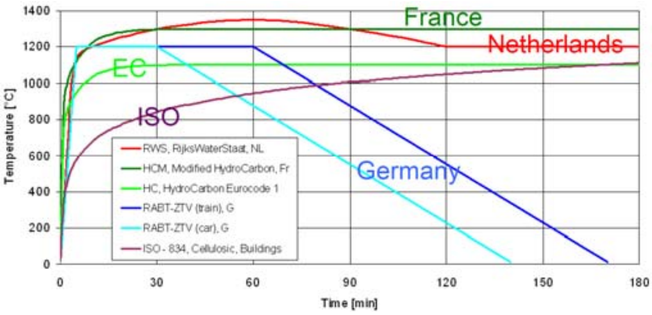

Fig. 5. International fire modeling.

In this regard, authors believe there is a need for development of a comprehensive technical document not only from structural performance perspective, but also from materials point of view. These may in turn change bridge design approaches such as the proposed importance factor by Kodur and Naser [19]. NCHRP in United States published “highway bridge fire hazard assessment” in 2013 which could be benchmarked for development of such a document [2].

V. Conclusion

There is a need for an efficient design of testing after a fire event on a bridge in order to ensure that the materials properties have not been jeopardised. This in turn requires a comprehensive technical procedure and such a document does not currently exist in Australia. The American “highway bridge fire hazard assessment” could be benchmarked for development of such a document.

Acknowledgment

The opinions and conclusions expressed in this paper are those of the authors and do not necessarily reflect the policies of Roads and Maritime.

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