FAILURE ON ENGINEERING STRUCTURES

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Abstract

On 1 August 2007, I - 35W Mississippi River Bridge collapsed by causing a hundred injuries and 13 deaths during the weekday rush hour, and causing about a hundred injuries and 13 deaths. After this tragic accident people realized the importance of the use of early warning systems for monitoring engineering structures. Thanks to the early warning systems, accidents can be estimated before they take place. According to a report in USA, more than 70 thousand bridges, which are used by approximately 300 million vehicles every day, have structural weaknesses. Engineering structures require maintenance after construction until end of their life expectancy. Engineer's responsibility is not only building the engineering structures in economical way but also ensuring their safety during their life expectancy.

In this study, potential reasons of the collapse of engineering structures are reviewed together with preventions of collapses by considering examples and the role of an engineer on these works and etiquette of engineers. Additionally, a new early warning system will be suggested for the bridges of Bosphorus and Fatih Sultan Mehmet (FSM) which bridge continents of Asia and Europe.

Introduction

During the history of civilization, people have changed the natural balance of the earth by not only polluting the environment but also constructing engineering structures such as buildings, bridges, dams, and etc. The reaction of the nature to these changes has appeared as earthquakes, tornados, floods or similar natural disasters and most of these reactions caused several deaths. For reducing human deaths in these disasters, people have tried to develop methods covering early warning systems or structural health monitoring. This is because previous heavy experiences of people show that It is possible to reduce the number of the deaths during natural hazards by the help of warning systems. As a result of Great Marmara Earthquake happened in 1999, people realized that these kinds of systems are also required for Turkey; hence, damage analyzing programs are started to be designed and developed.

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Firstly one must understand the reason of structure failure. Failure of a structure should be defined as partly or completely collapse of structure because of the tensile material of resistance is less than exterior tensile or exterior strain which should be exterior loading, weights, dynamic loading and etc. For overcoming a failure, uncertainty of the construction should first be solved. As emphasized by Latham (2007) risk, can be managed, minimized, shared, transferred or accepted, but it cannot be ignored. Therefore one can determine the uncertainty at six steps. These are design limitations, surveying, calculation or any kind of errors, organizational limitations of project, uncertainty at project, time restrictions.

On August 1, 2007 at 6.05 PM, steel deck truss bridge I – 35W over the Mississippi River, collapsed into the river during the weekday rush hour causing at least a hundred injuries and 13 deaths. This kind of events can happen any day in any country unless sufficient precautions are taken in to account while operating the engineering structures. Turkey has two important bridges, which connect the continents of Asia and Europe in Istanbul. Since approximately 400.000 vehicles everyday drive through these bridges, they are very important for transportation system. If one of these bridges was collapsed, the transportation system and economy would fall down. However, there is no an active early warning system in these bridges except for some short period researches.

In this paper, firstly collapse of I-35W bridge was examined in terms of bridge failures for introducing potential reasons that cause failures. Investigation of structural health monitoring systems is considered as another issue. Then finally the adaptive sensor system is suggested for Turkey's bridges.

Causes of Bridge Failures

The cause of structure failures should be known for getting information about the reasons of I -35W collapse. For that reason, analyzing failures of U.S. bridges is very beneficial. According to a research, 503 bridge failure cases occurred from 1989 to 2000 in U.S.A. The age of the failed bridges ranged from one year to 157 years (Wardhana, 2003). The reasons of bridge collapse are categorized as internal and external effects. The principal causes of bridge failures (internal effects) were categorized as deficiencies in design, detailing, construction, maintenance, use of materials and inadequate consideration of external events (Wardhana, 2003). Additionally, the external effects were categorized as vehicle impact, corrosive environment (like tornados, earthquake, flood, etc.) and terror attacks. Table 1 indicates the types of the bridges, employed material and number of failures. As it is clearly seen in the table material type of the bridge affects the total number of the failures. Bridges made of steel have 54.28% of all bridge failures; while concrete bridges have 12.53%. This compression shows that the material and type of the bridge are very important factors for the health of the bridge. Table 2 shows that, aside from external events, maintenance, and construction-related deficiencies predominantly caused the bridge failures (Wardhana, 2003).

Figure 1 shows peak occurrences of failures such as 1993, 1996 and 1989. Floods are the reasons of the peak in total number of collapsing bridge in both 1993 and 1996. The Loma Prieta earthquake is the reason of peak on 1989 (Wardhana, 2003). Between the years of 1989 and 2000, the average bridge failure is 42. Iowa and New York have big failure ratio in U.S.A. Iowa has this ratio because of flood, but the reason for New York is old bridges. The major causes of collapse are flood and corrosion. These examples show that the location, material of bridge and external effects have got a big importance on failure of bridges.

Table -1: Type and Number of Bridge Failures (Wardhana, 2003)

Bridge Type	Material	Number of Failures	Percentage
Arch	-	17	3.38
Beam/Girder	Concrete	29	5.77
-	Steel	145	28.83
-	Timber	13	2.58
-	Timber	5	0.99
Box Girder	Concrete	9	1.79
Corrugated pipe	Steel	4	0.80
Covered	Timber	6	1.19
Culvert	Steel	17	3.38
Slab	Concrete	25	4.97
Span	Steel	7	1.39
Truss	Steel	107	21.27
-	Timber	9	1.79
Floating	-	2	0.40
Pedestrian	-	2	0.40
Miscellaneous	-	61	12.13

Table-2: Number of Principal Causes of Failure (Wardhana, 2003)

Principal Cause	Collapse	Distress	Principal Cause	Collapse	Distress
Design	2	1	**Material**	4	2
Detaling	0	0	**External**	415	5
Construction	11	2	**Others (NA)**	17	1
Maintenance	37	6	**Total**	**486**	**17**

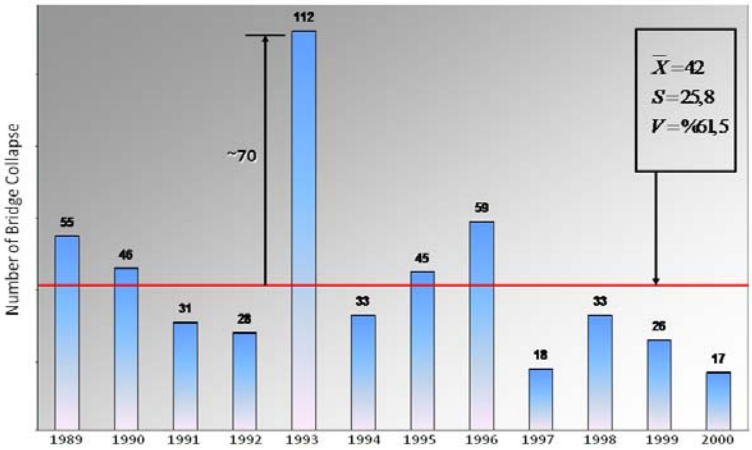

Figure- 1: Number of Bridge Collapse according to years (Wardhana, 2003)

Location and the Structure of I-35W

Bridge 9340 (of I-35W Mississippi River Bridge) was constructed in 1967, and has 14 spans, with a total length of 1,907 feet. The split deck has three through lanes each direction & also acceleration/deceleration lanes. The shoulders are only 2 ft. wide. The bridge deck widens at the north end to accommodate on & off ramps, and curves slightly at the south end. Along with the Plymouth Av. Bridge, the Interstate Hwy. 35W Bridge serves as the boundary that defines that the Mississippi Mile riverfront parkland. Stone Arch Bridge is positioned between the 3rd Av. Bridge and the Interstate Hwy. 35W Bridge (Figure-2). The bridge was one of the widest bridges in the Twin Cities area and provided an important link for Interstate 35W traffic. According to a 2005 report by the Minnesota Department of Transportation, 141,000 cars used the bridge each day. The superstructure of the bridge consisted of two main longitudinal trusses continuous over three spans of 81 m, 139 m, and 81 m. The longitudinal trusses were connected to each other with transverse trusses at each panel point (Figure -3).

Figure-2: The Satellite Image, Hybrid Image of I-35W Mississippi River Bridge

Cause of I – 35W Bridge Failure

The bridge was originally designed by Sverdrup & Parcel in 1965 using AASHO Specification 1961. Gusset plate U10 (Figure - 5) which is the gusset plate believed to have fractured first and started progressive collapse of the bridge is only ½ inch (26 mm) much less than what would be needed by design according to the governing specification (Astaneh-Asl,2008).

The deck initially had a thickness of about 16.5 cm, but during the 1977 – 1998 reconstruction an additional 5 cm wearing surface was added to the roadway making the total thickness of the roadway deck 22 cm (Astaneh-Asl, 2008).

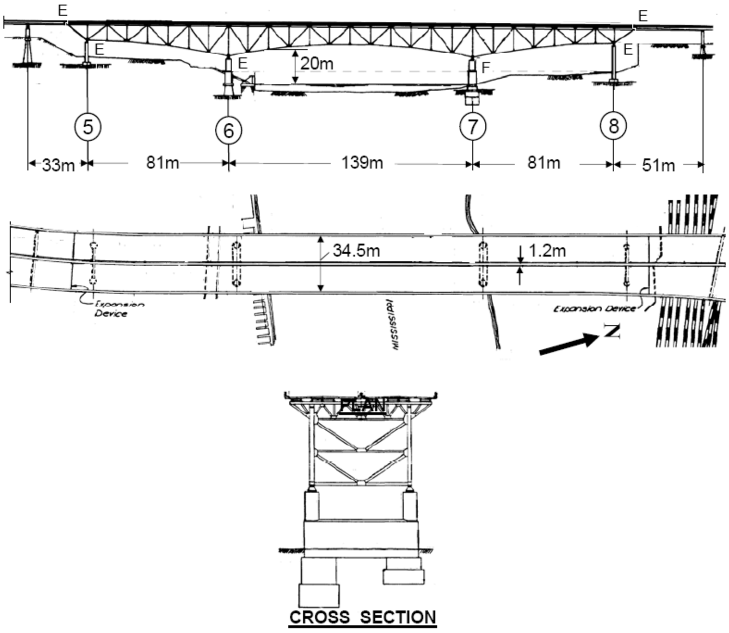

Figure -3: Structure of the I- 35W bridge (Astaneh-Asl,2008).

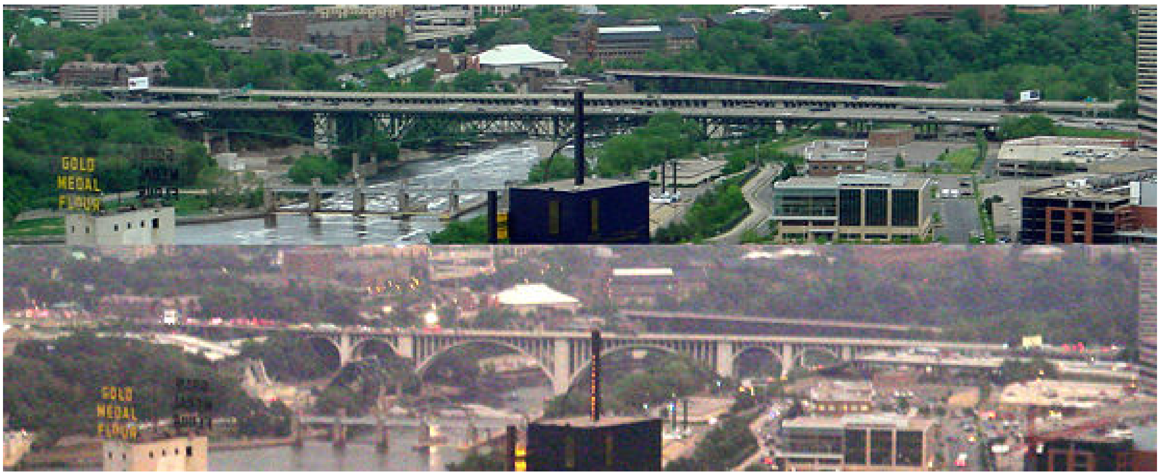

Figure – 4: Before and after collapse of I – 35W bridge

Figure – 5: Node U10 on east truss , scene from northeast; inside the structure

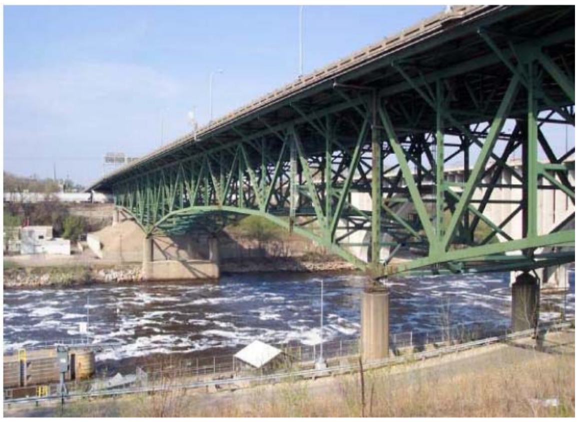

Figure – 6: General view before the collapse

Figure – 7: Parts of I – 35W bridge on 2006

A report was prepared on 2006 by Minnesota Department of Transportation; this report obviously indicates the main problem of the bridge. I – 35W had corrosion problems in the main river crossing (Figure – 7a, b). The bolted connections to the floorbeam trusses are "working" and some bolts are loose or missing (Figure – 7c). The truss members have numerous poor weld details (Figure – 7d).

Several weeks prior to the collapse, during the road construction, traffic is reduced to two lanes in each direction (Figure – 8). But the construction load on the bridge was extraordinarily heavy (Astaneh-Asl, 2008).

Depending on the above stated causes, the reason of the collapse should easily understand. The material of bridge was steel and had a lot of problems because of neglect. The extra weights and also additional wearing surface affects these corrosion parts and maybe gusset plate U10 thickness and collapse began.

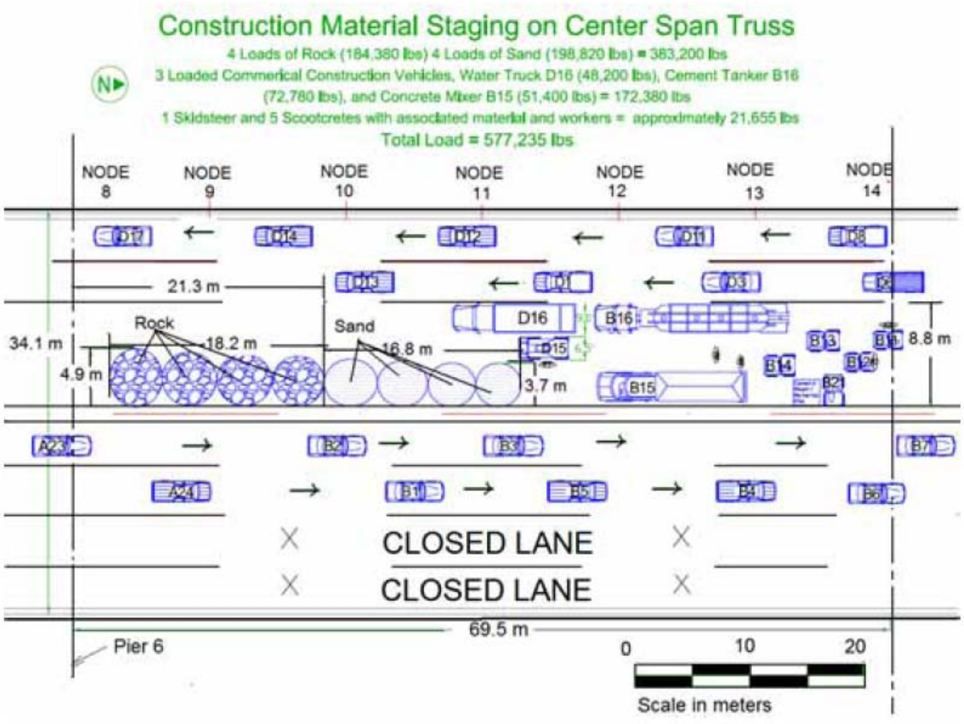

Figure – 8: Construction loads on the bridge according to a NTSB report (Astaneh-Asl, 2008).

Precautions of Disasters

To prevent failures of structures and saving lives, scientists try to estimate collapse before it began. There are a lot of options like GPS, wireless or GIS based data acquisition, transmission methods and data archival and management architectures for estimation of collapse, but the question is which is more beneficial or efficient. For better results, we need a live dynamic system, because it must give us instantaneous results. To solve this problem, structural health monitoring systems should be used. Structural Health Monitoring (SHM) has attracted much attention in both research and development in recent years. SHM refers to the use of *in – situ*, continuous or regular (routine) measurement and analyses of key structural and environmental parameters under operating conditions, for the purpose of warning impending abnormal states or accidents at an early stage to avoid casualties as well as giving maintenance and rehabilitation advice (NAN Li, 2004). In general SHM has three parts which are a sensor system, a data processing system and a health evaluation system. Sensors must give information us about stress, strain, displacement and acceleration. For this reason, in recent year's fiber optic sensors (FOS) are used. These sensors are used in Intelligent Sensing for Innovative Structures (ISIS, Canada) since 1993, Tsing Ma, Kap Shui Mun, Ting Kau, Commodore Barry, Benicia Martinez bridges and a lot of examples in Korea, Canada, India, Colombia and Europe. With these systems, even a low speed truck could be measured to estimate roughly the weight of the truck and its driving direction (NAN Li, 2004). FOS has a lot of advantages like long life cycle, high temperature endurance, flexibility, immunity to EMI, electrical isolation, quasi – distributed or distributed sensing capacity and economy (NAN Li, 2004). But this system is more beneficial for concrete bridges than steel ones, so overcome this problem for steel bridges Fibre Bragg grating (FBG) sensors should be used. FBG sensors have been established as a major leading technology as compared to other competing fiber optic sensor technologies and these sensors have attracted interest from the civil structure communities over the past decade for structural health, vibration and seismic response monitoring. The main advantages of FBG are small size, light weight, non conductivity, fast response, resistance to corrosion, higher temperature capability and immunity to electromagnetic noise and radio frequency interference (Majumder, 2008). These sensors were used with other systems in Tsing Ma, The Ting Kau, The Kap Shui Mun, The Horsetail Falls and The West Mill bridges and gave successful results.

Conclusion

This paper presents causes of bridge collapse with an example of failure which is I – 35W case, and the importance of early warning system or structure health monitoring. With an early warning system or SHM, the deformations, strain changes etc. should be determined before an accident and saving lives is possible.

The main cause of I – 35W collapse should be losing strength of an important part which is under corrosion or gusset plate U10 because of additional wearing surface or heavy construction load. So in all constructions we must try to overcome uncertainties. Computer software should be very beneficial at this situation. In design step of Tsing Ma, all internal and external loading possibilities were tried and when they saw the weaknesses of the bridge, they changed the design of bridge. And now this bridge is monitored with different early warning systems and SHM. These systems are very important for health of the bridge and the results should be beneficial for the other bridge design which will construct in other cities or countries.

As easily seen in Table – 1 and Table – 2, the most important reason for bridge failures is external effects. Steel bridges need more attention than concrete ones because of their corrosion sensitivity.

In all construction projects, an engineer has a lot of responsibilities. The engineer is responsible to people, other collogues, employer and own country. So an engineer must be honest, do the job perfectly, construct more economical and secure structures with best design, check and improve safety and sanitary conditions every day of construct, objective, not for being prejudice and only work for the human being happiness, safety and benefit (Mumcu, 1998).

Turkey has two important bridges in Istanbul. These bridges are very important for transportation system. Everyday 400.000 vehicles and about 1.000.000 people use these bridges. So an early warning system or SHM will be established as soon as possible. For that kind of system, using FBG sensors seem like the most appropriate method.

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