A redundancy truss system for cable-stayed and other bridge types with parallel edge beam structural systems for preventing catastrophic bridge failures. The system comprises one column with a plurality of cables supporting a bridge deck, where the cables are in tension, and the bridge deck is in compression, a roadway affixed to the bridge deck, at least one edge beam, a floorbeam, at least one traveler rail connected to the bridge deck, and light weight truss-style frames connected the cable-stayed bridge, where the light weight truss-style frames utilize conventional bridge elements in a multifunction capacity.
REDUNDANCY TRUSS FOR CABLE-STAYED AND OTHER BRIDGE TYPES

FIELD OF THE INVENTION
[0001] The present invention relates to bridge structural systems and more specifically to a redundancy truss system for cable-stayed and other bridge types with parallel edge girder structural systems that is simple to install and cost effective for preventing catastrophic bridge failure.

BACKGROUND
[0002] There are several bridge types that utilize steel edge girders as the overall structural system, as is often adopted for cable-stayed bridges, the edge girders and floorbeams are critically important for overall bridge stability. For this reason floorbeams have traditionally been designed to supplementary quality requirements as Fracture Critical Members (FCM), a mitigating measure defined in current building code provisions. However, the loss of an edge girder, floorbeam and deck has remained an un-mitigated vulnerability to catastrophic events such as an explosion or fire.
[0003] Industry-wide, there has been relatively little work in mitigation for this particular vulnerability, as the industry is just now adopting criteria for the performance of a new bridge of this type under these types of threats. One such criterion is Survivable Performance following a debilitating blast on a bridge deck. With a blast occurrence near the edge-of-roadway, i.e. in the zone of the edge girder(s), and absent of a redundant load path system, a blast of sufficient intensity is able to destroy the entire bridge.
[0004] With new performance criterion required for bridges was introduced, currently available solutions fell short of needed performance goals. Some suggested solutions include: box-style edge girder or multiple web edge girder, adding girder lines, providing for a stand-off distance by way of a wider bridge, adding a blast shielding such as a deck sandwich-plate.
Although multiple edge girders and box-style edge girders added strength to the design, each of these solutions is prohibitively expensive and an inefficient use of material. Additionally, these solutions add significant weight and maintenance to the bridge.

[0005] Therefore, there is a need for a redundancy truss system for cable-stayed and other bridge types with parallel edge girder structural systems that is simple to install and cost effective for preventing catastrophic bridge failures.

SUMMARY

[0006] The invention is a redundancy truss system designed to prevent catastrophic bridge failures for cable-stayed and other bridge types with parallel edge beam structural systems. A cable-stayed bridge comprises at least one column with a plurality of cables supporting a bridge deck, where the cables are in tension and the bridge deck is in compression. There is at least one roadway affixed to the bridge deck, with at least one edge beam, and at least one floorbeam. The invention comprises a cable-stayed bridge, at least one traveler rail connected to the bridge deck, and at least one light weight truss-style frame connected to the cable-stayed bridge. The light weight truss-style frames utilize conventional bridge elements in a multifunctional capacity.

[0007] The light weight truss-style frames are made up of at least one element forming a redundancy truss web connected to at least one traveler rail, and at least one deck panel support beam connected to the redundancy truss web elements and the traveler rail. The light weight truss-style frames are designed to support the roadway in the event of a transverse beam (floorbeam) failure. The light weight truss-style frames distribute loads across a failed transverse beam to prevent the catastrophic failure of the bridge. The frames achieve this by integrating with conventional bridge elements to form a multifunctional structural redundant load path.

[0008] Fracture Critical Members are tension members or tension components of members whose failure would be expected to result in collapse of the bridge. One advantage to the current invention is that floorbeams can be removed from FCM status because a
number of the lightweight truss-style frames are connected to the cable-stayed bridge. A second advantage to the current invention is that the cable-stayed bridge structural framing can be robustly braced for temporary construction loads. A third advantage is that the lightweight truss-style frames are an erection stability aid for the cable-stayed bridge. The lightweight truss-style frames also provide built-in redundancy.

The web elements, deck panel support and traveler rail can be fabricated from any metal sufficient to provide the strength necessary to keep the bridge intact for any given event using standard calculations. In order to reduce cost and weight, the redundancy truss web elements, the deck panel support and the traveler rail can be fabricated from aluminum.

The current invention can be used to permanently upgrade an existing cable-stayed bridge in order to prevent catastrophic loss. A computer structural analysis can be used to determine the redundancy necessary to meet performance goals. Then, the existing bridge can be retro-fitted with at least one lightweight truss-style frame that is compatible with the existing structure.

The current invention can also be utilized in a temporary fashion. One example is if only a temporary upgrade is needed in order for the bridge to support temporary construction loads. Once the performance goals are determined using a computer structural analysis, at least one lightweight truss-style frame that is compatible with the existing structure can be temporarily affixed to the cable-stayed bridge.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other features, aspects and advantages of the present invention will become better understood with regard to the following description, appended claims, and accompanying figures where:

Figure 1 is a side view of a cable-stayed bridge;
Figure 2 is a top view of a roadway that comprises part of the cable-stayed bridge of Figure 1;
Figure 3 is a cross section diagram of the roadway of Figure 2 identifying the location of a traveler rail of the bridge in Figure 1; Figure 4 is a cross section diagram of the roadway of Figure 2 identifying the location of a potential catastrophic event to the bridge in Figure 1; Figure 5 is a schematic diagram of a redundancy truss system showing flow of forces when a supporting edge girder is disabled and a truss must support a floorbeam in order to prevent the catastrophic event of Figure 4 from destroying the bridge of Figure 1; Figure 6 is a top mechanical structural framing plan view of the location of the traveler rail for the bridge of Figure 1; Figure 7 is a top mechanical structural framing plan view of the location of the expansion joint brackets and counterweight diaphragams in relation to the traveler rails for the bridge of Figure 1; Figure 8 is a cross sectional view of elevation floorbeams for the bridge in Figure 1; and Figure 9 is a close up view of the redundancy truss system of Figure 5.

DETAILED DESCRIPTION

This invention introduces a very simple structural framing system that not only introduces necessary redundancy, but uses bridge elements that are already typical on bridges of this type and are therefore inherently cost effective. Specifically, there is presented a system and method to incorporate a customary Traveler Rail and a typical Deck-Panel-Support-Beam into a redundancy truss that serves multiple functions, including mitigating the aftermath consequences of a damaging deck-level blast. In short, this innovative system maintains the support of transverse floorbeams even with the loss of the adjoining deck and steel edge girder. The above is critical to achieve in order that the overall bridge survive the damage.

This approach has been achieved by way of integrating conventional bridge elements into a multi-function system that serves as a redundant load path structural system.
The present invention has the further advantages of allowing the floorbeams to be removed from FCM status, thus saving costs in initial construction and also in service-life through reduced inspection effort(s). The system also benefits construction in that the structural framing can be robustly braced for temporary construction loads by mobilizing the structural system intended for other purposes, as described above. As can be appreciated, the removal of FCM from a bridge is not only desirable from the perspective of public safety, but necessity cost savings as well.

[00024] Methods and devices that implement the embodiments of the various features of the invention will now be described with reference to the drawings. The drawings and the associated descriptions are provided to illustrate embodiments of the invention and not to limit the scope of the invention. Reference in the specification to "one embodiment" or "an embodiment" is intended to indicate that a particular feature, structure, or characteristic described in connection with the embodiment is included in at least an embodiment of the invention. The appearances of the phrase "in one embodiment" or "an embodiment" in various places in the specification are not necessarily all referring to the same embodiment.

[00025] Throughout the drawings, reference numbers are re-used to indicate correspondence between referenced elements. In addition, the first digit of each reference number indicates the figure where the element first appears.

[00026] As used in this disclosure, except where the context requires otherwise, the term "comprise" and variations of the term, such as "comprising", "comprises" and "comprised" are not intended to exclude other additives, components, integers or steps.

[00027] In the following description, specific details are given to provide a thorough understanding of the embodiments. However, it will be understood by one of ordinary skill in the art that the embodiments may be practiced without these specific details. Well-known circuits, structures and techniques may not be shown in detail in order not to obscure the embodiments. For example, circuits may be shown in block diagrams in order not to obscure the embodiments in unnecessary detail.
Also, it is noted that the embodiments may be described as a process that is depicted as a flowchart, a flow diagram, a structure diagram, or a block diagram. Although a flowchart may describe the operations as a sequential process, many of the operations can be performed in parallel or concurrently. In addition, the order of the operations may be rearranged. A process is terminated when its operations are completed. A process may correspond to a method, a function, a procedure, a subroutine, a subprogram, etc. When a process corresponds to a function, its termination corresponds to a return of the function to the calling function or the main function.

In the following description, certain terminology is used to describe certain features of one or more embodiments of the invention.

The term "Fracture Critical Members" (FCM) refer to tension member(s) or tension component(s) of member(s) whose failure would be expected to result in collapse of a bridge.

Various embodiments provide a system and installation method for a redundancy truss system for cable-stayed and other bridge types with parallel edge girder structural systems that is simple to install and cost effective for preventing catastrophic bridge failures. The system and method will now be disclosed in detail.

Referring now to Figure 1, there is shown a side view of a cable-stayed bridge 100. As can be seen, a typical cable-stayed bridge is a bridge that consists of one or more columns 102 and 104, normally referred to as towers or pylons, with cables 106 supporting the bridge deck 108. According to the North American Cable Stay Bridge Registry, there are currently 63 major cable-stayed bridges in North America alone. There are many more minor cable-stayed bridges that are can be found throughout North America. Around the World cable-stayed bridges can be found in increasing number.

The cable-stayed bridge 100 lacks the great rigidity of a trussed cantilever bridge, and the continuous beam shown in Figures 6 and 7, compensates for this. Advantageously, there is no need for anchorage's to sustain strong horizontal forces, as in a suspension bridge, because the spans are self-anchoring. Cable-stayed bridges 100 can be
cheaper than suspension bridges for a given span and many asymmetrical designs are possible.

As can be appreciated, the maintenance and prevention of the loss of any of these bridges is a major concern due to accidents or purposeful intent. In a cable-stayed bridge 100, the cables 106 are in tension, and the deck 108 is in compression.

Referring now to Figure 2, there is shown a top view of a roadway 200 that comprises part of the cable-stayed bridge 100. In this example, there are two different roadways 202 and 204 that make up the cable-stayed bridge 100. A single roadway 202 or even more roadways are possible using the cable-stayed bridge design.

Referring now to Figure 3, there is shown a cross section diagram 300 of one roadway 202 identifying the location of one or more than one traveler rail 302 and 304 of the bridge 100. At least one traveler rail 302, often used for bridge inspections, is part of the bridge roadway 202. The traveler rail 302 will be used in this invention to reinforce the different bridge sections.

Referring now to Figure 4, there is shown a cross section diagram 400 of the roadway 202 identifying the location of a potential catastrophic event 402 to the bridge 100. Without the support of the floorbeam 404 in the area, damage to this area can cause a catastrophic failure of the bridge 100 causing the entire bridge 100 to collapse. Hence the FCM status of the floorbeam 404.

Referring now to Figure 5, there is shown a schematic diagram of a redundancy truss system showing flow of forces when a supporting edge girder is disabled and a truss must support a floorbeam in order to prevent the catastrophic event of Figure 4 from destroying the bridge 100. As can be seen, the redundancy truss system 500 shows how forces 502, 504, 505, 506, 507, 508 and 510 flow when a supporting edge girder 512 is disabled and the truss system 500 must support a floorbeam 404 to prevent the catastrophic event 402 from destroying the bridge 100. As can be seen, the maintenance traveler rail 302 is used as part of the redundant truss system 500 described herein. The failure of the edge girder 512 can cause the roadway 200 to project a downward force 502 along the floorbeam
404. Normally, this would result in the total failure of the bridge 100 in a cascading fashion. However, due to the truss system 500 formed by the traveler rail 302, double angle elements 514 and 516, and the deck panel support beam 518 the damaged floorbeam 404 remains supported and hence the roadway deck 200 remains competent in supporting the global compression forces of the deck system. The force vectors 502, 504, 505, 506, 507, 508 and 510 show how the load from the floorbeam 404 would be distributed across the traveler rail 302, the double angle girders 514 and 516 and other support structures 518. The redundancy truss system 500 prevents the catastrophic failure of the bridge 100.

[00039] Referring now to Figures 6 and 7, there are shown top mechanical structural framing plans 600 and locations of expansion joint brackets and counterweight diaphragams 700 in relation to the traveler rails 302 and 304 for the bridge 100. As can be seen, there are many sections to a cable-stayed bridge 100 that would need to be retro-fitted with any system to prevent a catastrophic loss. Therefore, it is imperative that any design be compatible with the existing structure and cost effective. The invention described herein provides both.

[00040] Referring now to Figure 8, there is shown a cross sectional view of an elevation floorbeam 800 for the bridge 100. As has been previously discussed, the floorbeam 802 of a cable-stayed bridge 100 support the roadway deck 202, which is under compression.

[00041] Referring now to Figure 9, there is shown a close up view of the redundancy truss system 500. As can be seen the redundant truss system 500 for cable-stayed 100 and other bridge types with parallel edge girder 512 structural systems that is simple to install and cost effective for preventing catastrophic girder failures comprises: an angle beam 514, a traveler rail 302, and a deck panel support 518. The angle beam 514, deck panel support 518 and traveler rail 302 can be fabricated from any metal sufficient to provide the strength necessary to keep the bridge intact for any given event using standard calculations. In a preferred embodiment the angle beam 514, deck panel support 518 and traveler rail 302 are fabricated out of aluminum to reduce both cost and weight.

[00042] The system integrates conventional bridge 100 elements into a multi-function system that serves as a redundant load path structural system. The system 900 has the further
advantages of allowing the floorbeams 404 to be removed from FCM status, thus saving costs in initial construction and also in service-life through reduced inspection effort(s). The system 500 also benefits construction in that the structural framing can be robustly braced for temporary construction loads by mobilizing the structural system intended for other purposes, as described above. The system 500 has obvious advantages over using box-style edge girder 512 or a multi-web edge girder 512 that are much less efficient overall and costlier.

[00043] The present invention overcomes the cost and inefficient blockades predominantly by incorporating a light weight truss-style framing system 500 that utilized conventional bridge elements in a multi-function capacity. By providing a technical solution of built-in redundancy with only minor added structural elements, the system provides a low cost solution that has an offsetting upside in the large-scale by eliminating the FCM status of the floorbeams and also serving as an erection stability aid. Overall, the system can be a zero-cost advantage, or considering the lifecycle of the bridge, a net facility savings.

[00044] Computer structural analysis has proven that the system is effective and that, in fact, for a large blast the redundancy is necessary to meet performance goals. The system is simple and can be proven to serve its purpose with simple hand computations if necessary.

[00045] What has been described is a new and improved system and method for a redundancy truss system useful for preventing the total loss of a bridge in the event of certain catastrophic events, overcoming the limitations and disadvantages inherent in the related art.

[00046] Although the present invention has been described with a degree of particularity, it is understood that the present disclosure has been made by way of example. As various changes could be made in the above description without departing from the scope of the invention, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be illustrative and not used in a limiting sense.
What is claimed is:

1. A redundancy truss system for cable-stayed and other bridge types with parallel edge beam structural systems for preventing catastrophic bridge failures, the system comprising:
   a) a cable-stayed bridge comprising:
      1) one or more than one column with a plurality of cables supporting a bridge deck, where the cables are in tension, and the bridge deck is in compression;
      2) one or more than one roadway affixed to the bridge deck;
      3) one or more than one edge beam connected to the bridge deck;
      4) one or more than one floorbeam affixed to the bridge deck;
   b) at least one traveler rail connected to the bridge deck; and
   c) one or more than one light weight truss-style frames connected to the cable-stayed bridge, where the light weight truss-style frames utilize conventional bridge elements in a multifunction capacity.

2. The light weight truss-style frames comprising:
   a) one or more than one element forming a redundancy truss web connected to the at least one traveler rail; and
   b) one or more than one deck panel support beam connected to the redundancy truss web elements and the traveler rail.

3. The system of claim 2, where the light weight truss-style frames are designed to support the roadway in the event of a transverse beam (floorbeam) failure.

4. The system of claim 3, where the light weight truss-style frames distribute loads across a failed transverse beam to prevent the catastrophic failure of the bridge.

5. The system of claim 3, where the light weight truss-style frames integrate with conventional bridge elements to form a multifunctional structural redundant load path.
6. The system of claim 3, where the web elements, deck panel support and traveler rail are fabricated from any metal sufficient to provide the strength necessary to keep the bridge intact for any given event using standard calculations.

7. The system of claim 6, where the redundancy truss web elements, the deck panel support and the traveler rail are fabricated from aluminum to reduce cost and weight.

8. The system of claim 3, where a number of the light weight truss-style frames are connected to the cable-stayed bridge such that the floorbeams can be removed from FCM status.

9. The system of claim 2, where the cable-stayed bridge structural framing can be robustly braced for temporary construction loads.

10. The system of claim 2, where the light weight truss-style frames provide built-in redundancy.

11. The system of claim 2, where the light weight truss-style frames eliminate the FCM status of the floorbeams.

12. The system of claim 2, where the light weight truss-style frames are an erection stability aid for the cable-stayed bridge.

13. A method for a redundancy truss system for cable-stayed and other bridge types with parallel edge beam structural systems for preventing catastrophic bridge failures, the system comprising:
   a) providing the system of claim 1;
b) providing a computer structural analysis to determine the redundancy necessary to meet performance goals; and

c) retro-fitting the cable-stayed bridge with the one or more than one lightweight truss-style frame to prevent a catastrophic loss, where the one or more than one lightweight truss-style frame is compatible with the existing structure.

14. A method for a redundancy truss system for cable-stayed and other bridge types with parallel edge beam structural systems for preventing catastrophic bridge failures, the system comprising:

a) providing the system of claim 1;

b) providing a computer structural analysis to determine the redundancy necessary to meet performance goals; and

c) temporarily affixing the one or more than one lightweight truss-style frame to the cable-stayed bridge for temporary construction loads, where the one or more than one lightweight truss-style frame is compatible with the existing structure.
STRUCTURE FRAMING PLAN

Figure 7

ELEVATION FLOOR SHEET CORP

Figure 8
Figure 9