A Temporary Bridge

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The paper by Wattenburg *et al.* in this issue (*1*) presents the design and dynamic characteristics of a modular steel bridge. The California Department of Transportation (Caltrans) determined that this modular bridge could have been used for emergency freeway repairs after the 1994 Los Angeles earthquake had it been available in time. Caltrans has now developed an inexpensive freeway bridge kit that other transportation agencies can easily build and store in central locations for rapid repair of bridges damaged by floods or earthquakes. This modular bridge design may also provide safe, multilane permanent bridges for many areas that cannot build standard bridges because of expense or environmental considerations.

The Northridge earthquake damaged some of this country's most heavily traveled freeways. The travel schedules of a half million people in Los Angeles were interrupted for months with great economic loss. Caltrans engineers explored every reasonable way to open the Los Angeles freeways more quickly with temporary bridges, but no workable multilane temporary bridges were available that could restore even minimal traffic flow. After reconstruction began, Professor Astaneh-Asi (University of California, Berkeley) informed Caltrans about a modular temporary bridge design proposed by Wattenburg. To be sure, we were initially skeptical about the practicality of a freeway bridge built with, of all things, huge railroad flatcar decks. However, we decided to build and test a prototype as quickly as possible because of the possibility of more earthquake damage while the Los Angeles freeway bridges were being rebuilt.

An experienced bridge contractor, MCM Inc. of North Highlands, California, was employed to construct the first four-lane flatcar bridge with Wattenburg's assistance. They completed the prototype in 10 working days. This alone was a significant indication of its potential usefulness as an emergency replacement bridge. When the bridge was built and standing, we realized the versatility of the well-engineered flatcar modules and the manner in which they can be interconnected without the need for bolted or welded brackets to create a strong modular bridge that can carry freeway traffic. The prototype experiments demonstrated that this modular bridge could be erected at most any site in a few days' time.

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The Livermore Laboratory dynamic analysis calculations have answered the critical question of what will happen to a high, stand-alone section of this temporary freeway bridge if it experiences a strong aftershock while it is being erected. These new calculations give us some confidence that neither the interlocking joints nor the structural modules will fail and cause collapse of the bridge during strong aftershocks.

Caltrans has now completed a field-ready version of the bridge that will span a 50-m gap, complete with a modular extruded metal roadway deck. This is adequate to replace most four-lane highway overpass structures or damaged sections in freeway bridges such as those that collapsed on the Santa Monica freeway (*2*). Three mechanics with a 27-metric-ton crane were able to disassemble the completed four-lane bridge and load it on trucks in 6 hours. All modules of the bridge are now stored as a kit for rapid deployment. The bridge kit has been moved to the Lost Hills maintenance station, just off Interstate 5 near the geographic center of the state, providing easy and rapid transport to any part of California. Currently, the Caltrans Bridge and Structures Maintenance Office is developing a bridge assembly (bridge kit) handbook so that nearly any maintenance crew can put the bridge in place. I estimate that this temporary bridge can be on site 1 day after an event and can be erected in less than a day.

Field Specifications

The Caltrans' modular bridge consists of a stand-alone, four-lane, 16-m-long center section with two column structures 8 m high, as shown in the design drawings in the paper by Wattenburg *et al.* We extended the roadway on either side of this center section with eight additional flatcar modules to connect to existing structures or abutments and provide a four-lane bridge that spans a 50-m gap. The roadway is 14.5 m wide. This provides four 3- to 3.4-m lanes in one direction or two 3-m lanes each way with a concrete K-rail median barrier. This bridge can be lengthened in 16-m increments by adding more center sections as desired, with only one additional column (bent) structure required for each additional center section. Each add-on 16-m section requires seven more flatcars.

Live load capacity of our flatcar bridge far exceeds the AASHTO (American Association of State Highway and Transportation Officials) loading specifications because the flatcars are each designed for over 45,000 kg tare. The flatcar roadway is substantially overdesigned compared to the support beams used in a normal steel bridge. We test loaded the four lane, 16-m-long center span with over 100 metric tons of steel beams and concrete K-rail at mid-span. The deflection at mid-span was 3.2 mm.

Speeds allowed on the flatcar bridge can be in the range of 80 km per hour because it has an open grid steel deck, similar to that on the moveable bridges throughout the country. The entire flatcar bridge can be moved quickly by commercial movers or by agency maintenance vehicles. The flatcar modules are, however, 16.8 m long and weigh 3 metric tons. Our 50-m bridge is nine loads for an 18-wheeler semitruck with two flatcars per truck load.

Costs and Other Factors

The finished cost of our 50-m modular bridge was approximately $263,000, but much of this cost was for prototype experimentation, load testing, and transportation to the storage site. The steel grid deck was $93,000 of the total cost because it had to be purchased new. Even this $263,000 cost is approximately only one-half the cost of a typical permanent bridge design requiring months to construct on site. For a longer duration at the site, a thin (10 cm) concrete deck could be poured in place with some steel mesh reinforcing. This would be much less expensive than the steel grid roadway we purchased. We believe that our 50-m bridge could be duplicated for less than $150,000 with such a concrete roadway deck.

This bridge is environmentally friendly. Little ground disturbance is necessary to erect the bridge. It can be dismantled quickly and returned to inventory for future use with no loss of materials after construction of a new bridge is complete. This will be important for temporary, or even permanent bridges, over environmentally sensitive areas such as creek beds and wetlands where extensive excavation is precluded. The bents (columns) rest on full-length flatcar modules (49 m^2 each) which are the bridge footings. Some leveling of the ground is all that is required because most soils can provide resistance of 4900 kg m^{-2}.

The railroad flatcar modules used in this bridge are readily available throughout the country. In addition to the flatcars available in surplus yards, there are thousands more in the rolling stock of the U.S. railroads. In an emergency, they can be delivered by the railroads to almost any site. Flatcar decks are not welded or bolted to the wheel trucks that support them. The flatcars can be lifted quickly off the wheel trucks and used to build this modular bridge with little modification to the decks. Caltrans anticipates the necessity of building more of these modular bridges on site with flatcars delivered by the railroads should a disaster occur that damages many freeway bridges at one time.

Uses of the Bridge

In a state that suffers floods, forest fires, and earthquakes, a modular transportable bridge can be of great value to the public. This modular bridge design may be cost-effective in some cases even if the structural modules are built from new steel I-beams rather than using surplus railroad flatcars. The time saved in responding to emergencies in California could offset even much greater costs than Caltrans paid for our present version of this modular bridge.

Other countries have inquired about the modular bridge. Some of these countries need inexpensive bridges whose components can withstand an earthquake or a flood. A dislodged or toppled version of this modular bridge can be taken apart and put back together again quickly. The strong flatcar modules will seldom be damaged. Most modern permanent bridges are seriously or completely damaged when dislodged from their supports.

Many small communities cannot afford standard bridges over dangerous grade crossings. A typical four-lane prestressed concrete bridge over a railroad or busy thoroughfare will cost a $1 million or more. The 50-m-long, four-lane modular bridge Caltrans has developed will safely span the typical grade crossing. With a concrete roadway deck, it can be built and erected for less than $200,000. At level grade crossings, the only other requirements are the earthwork approaches to the bridge. Esthetics are not the major factor for many communities and underdeveloped countries compared to safety and basic transportation that could not be achieved otherwise. The esthetics of the flatcar bridge can be improved in many inexpensive ways with local labor and materials. Subsequent maintenance is no more expensive than for any other steel bridge.

As the chief engineer for this country's largest freeway and bridge building agency, I must add that this project was a good example of how our scientific laboratories can help public agencies with major infrastructure problems. With the initiative and assistance of scientists, Caltrans was able to transform this idea into field-ready equipment in a few months' time—at less expense than the cost for emergency repair of just one of our recently damaged freeway bridges. Transportation agencies that chose to use this modular bridge will have uncommonly inexpensive new technology to restore vital transportation over damaged freeways within a few days instead of many months. This should result in great savings to taxpayers in the future, and, hopefully, motivate even more innovative bridge designs.

REFERENCES AND NOTES

1. W. H. Wattenburg, D. B. McCallen, R. C. Murray, *Science* **268**, 279 (1995).
2. Caltrans has now used the modular flatcar bridge to construct a temporary bridge to reopen Interstate 5. A 100-km stretch of this vital north-south transportation route on the West Coast was closed on 11 March 1995, after flood waters destroyed twin 36-m concrete bridges near Coalinga, CA. A 50-m-long temporary bridge was erected over the gap in six working days. Steel pilings were driven into the river bottom to provide a platform for the bridge while flood waters continued to flow through the gap. The flatcar module bridge deck was assembled 16 hours after the support pilings were in place. The freeway was reopened with one lane of traffic in each direction on 18 March, with normal weight limits allowed over the temporary bridge. New bridges can now be constructed on either side of the temporary bridge without interruption of traffic flow. Major California freeways suffering similar damage in the past have typically been closed for several months because the only option was to wait for reconstruction of new bridges.