Study on Rapid Assessment of Traffic Capacity of Girder Bridges Post Major Earthquake

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Abstract. To provide a highly applicable tool, which can assess the damage level and traffic capacity of girder bridges accurately and quickly, we proposed a new rapid assessment model for girder bridges, which contains a vulnerability model with parameter modification and a fast evaluation method for traffic capacity. Based on this model, we developed a rapid assessment software for girder bridges, using Visual C++ and ArcGIS Engine, in which the damage level and traffic capacity of girder bridges post-quake can be highlighted with colourful segments in the road network. Furthermore, we illustrated the functions and usages of this software through an application example.

Keywords. Rapid assessment, traffic capacity, girder bridges.

1. Introduction
Highway network is the most important lifeline system, which daily transports numerous supplies and passengers, connecting cities and villages intimately [1]. Bridges are key nodes in a highway system. Once a bridge becomes inaccessible, the segments controlled by it will fail immediately, and the capacity of road network nearby will be influenced indirectly [2-3].

Compared with arch bridges and tunnels, girder bridges are more vulnerable than other nodes under the action of strong ground motion. In a major earthquake, some girder bridges (especially old girder bridges) in disaster area will be damaged in different degrees. Their functional state have great influence to the work of rescue and relief. For instance, in the great Wenchuan earthquake, more than 650 bridges were damaged badly (most were girder bridges), so the roads that provided access to all the affected villages and counties were disrupted. External aid could not be delivered in time and relief supplies could not be rushed to the disaster areas [4].

Therefore, the damage levels of girder bridges and their traffic capacity after a major earthquake are crucial information that should be obtained as soon as possible. It is an important prerequisite for effective emergency commanding and relief operations. However, it is impracticable to check up all bridges on site in a very short time. Although some new developed techniques (such as remote sensing, disaster monitor, UAV, etc.) have shown great potential in seismic damage identification, none of them can fully meet the actual needs of post-earthquake emergency in accuracy and practicability [5].

As an applicative method, rapid assessment technique can estimate the damage levels and functional states of structures in minutes to several hours. For girder bridges, assessment model and
assessment software are mainly concerned. In the past decades, several assessment model for girder bridges were proposed [6-10]. Among them, Shinozuka model is more applicable. However, its fragility curve was derived from statistical results, without taking the specific conditions of each bridge into account.

To assess the damage level and traffic capacity of single girder bridge accurately and quickly, we investigated the rapid assessment method and software developing technique for traffic capacity of girder bridges after a major earthquake.

2. Assessment Model

2.1. Seismic Vulnerability Model for Girder Bridges with Parameter Modification

To assess the damage level of a single girder bridge accurately, we improved the Shinozuka vulnerability model [9] with parameter modification, in which the specific conditions of each bridge are expressed explicitly, identified by four crucial structural parameters. All fragility curves are represented by two-parameter lognormal distribution functions. The equation for improved model is:

\[ F_j(I_i; \kappa_j, \lambda_j) = \Phi(\lambda_j^{-1} \cdot \ln((I_i + \eta) \cdot \kappa_j^{-1}) \]  

(1)

where \( \kappa_j \) and \( \lambda_j \) are the median and log-standard deviation of the fragility curves for the damage state of “at least minor”, “at least moderate”, “at least major” and “collapse” (identified by \( i = 1, 2, 3, 4 \) respectively). The equation of the correction factor \( \eta \) is described as:

\[ \eta = \eta_1 + \eta_2 + \eta_3 + \eta_4 \]  

(2)

where, \( \eta_1, \eta_2, \eta_3, \eta_4 \) are the impact factors to fragility of girder bridges, caused by spans number, building year, site type and fortification intensity respectively (See in tables 1-4).

| Table 1. Values of \( \eta_1 \). |
|----------------------------------|
| Spans of Bridge | \( \leq 3 \) | >3 |
| \( \eta_1 \) | -0.5 | 0.5 |

| Table 2. Values of \( \eta_2 \). |
|----------------------------------|
| Building Year | Before 1977 | 77-85 | 86-89 | After 1999 |
| \( \eta_2 \) | 1.0 | 0 | -0.5 | -1 |

| Table 3. Values of \( \eta_3 \). |
|----------------------------------|
| Site Type | I | II | III | IV |
| \( \eta_3 \) | -1 | 0 | 2 | 3 |

| Table 4. Values of \( \eta_4 \). |
|----------------------------------|
| Fortify Intensity | Lower | Equal | Higher |
| \( \eta_4 \) | 1.0 | 0 | -1.0 |

2.2. Fast Evaluation Method for Traffic Capacity

The Modified Capacity constraint-Incremental Assignment Method [11] was utilized. According to the datum from numerous seismic investigation in major events, we found that there is an obvious corresponding relationship between the damage level of a girder bridge and its post-quake traffic capacity (as shown in table 5).

For rapid assessment, we obtain the percentage of each damage state of a bridge firstly. Then we calculate its traffic assignment value using equation (3):
TA = \sum_{j=1}^{5} P_{ij} \cdot K_j \quad \text{(3)}

where, TA is the traffic assignment value; \( P_{ij} \) is the percentage of various damage states; \( K_j \) is the nominal value of various damage states.

The traffic capacity is determined according to table 5 finally.

| Damage Level   | Intact | Minor | Moderate | Major  | Collapse |
|----------------|--------|-------|----------|--------|----------|
| \( K_j \)     | 1.0    | 0.8   | 0.65     | 0.3    | 0        |
| TA             | 0.85~1.0 | 0.75~0.85 | 0.5~0.75 | 0.3~0.5 | 0~0.3    |
| Traffic Capacity | Passable | Passable | Uncertain | Impassable | Impassable |

3. Assessment Software

Based on the proposed assessment model, we developed a rapid assessment software for girder bridges, aimed to be highly applicable for post-earthquake emergency commanding and relief operations.

3.1. System Design

Considering the actual needs of post-earthquake assessment, the software must meet two requirements as follows: 1) Providing assessment results as soon as possible; 2) Displaying the assessment results in road network on a map, to support further analysis on traffic capacity of affected areas. Therefore, a fast programming language and GIS components are badly necessary.

In this paper, we utilized Visual C++ to develop the assessment software, in which ArcGIS Engine was taken as underlying driver. The major advantage of ArcGIS Engine is that it can be independently used outside the large framework of ArcGIS Desktop. It can combine with many mainstream programming languages and the developed applications can run independently.

To access the parameters of girder bridges efficiently, fundamental geographic data of earthquake area is stored locally in form of shapefiles, which can be preloaded before assessment calculation. Moreover, we selected the basic parameters of earthquake as input data, which can be obtained soon after a major event. The blueprint of this software is shown in figure 1.

3.2. System Implementation

As a typical customized GIS application, necessary components provided by ArcGIS Engine were added into the Visual C++ project first. Among them, MapControl, TOCControl, Carto, Display and Geometry are mainly for map showing; Geodatabase, DataSourceFile and DataSourceRaster are for data accessing; others (such as System, SystemUI, Output, etc.) provide fundamental GIS functions.

In most fundamental geographic data, we can usually find the bridge layer, which contains crucial structural parameters. By searching the data table for girder bridges, we obtained the parameters necessary for the assessment. To accept the earthquake parameters, an input dialog was utilized.
In the assessment module, we got the damage level of each girder bridge firstly, then the traffic capacity. We stored them in two data fields that were inserted into the girder bridges data table. The assessment results in form of text can be seen immediately by displaying them in a tableview control.

In the map rendering module, the assessment results are displayed in the bridge layer. We rendered girder bridges in different damage level (or traffic capacity) with different colors, to highlight their states in the road network clearly.

4. Example

4.1. Assessment

Using the geographic data for a district of Shanghai, we assessed 12 girder bridges over Suzhou River (as shown in figure 2). For there were rarely major events, the parameters of earthquake were assumed (as shown in figure 3). The assessment results in text form were displayed in figure 4.

![Image 1](image1.jpg)

**Figure 2.** Bridges to be assessed and road network in the studied area.

![Image 2](image2.jpg)

**Figure 3.** Input earthquake parameters.

![Image 3](image3.jpg)

**Figure 4.** Assessment results (in tableview).
4.2. Display in Road Network

Obviously, the textual assessment results can only provide scattered information about girder bridges themselves, without indicating their influence to the road segments surrounding. Therefore, we also displayed the assessment results on a GIS map, by rendering the damaged bridges with colourful figures in the road network.

The damage states and traffic capacity of these bridges were presented on the map respectively. In damage states mode (as shown in figure 5), specific color indicates specific damage level (green for intact, cyan for minor, yellow for moderate, pink for major, and red for collapse). From this map, we can clearly find that there were two regions in which several neighbouring bridges were badly damaged, what means that traffic capacity within these regions decreased dramatically. The bridges in yellow should be recheck on-site and repaired in rush.

In traffic capacity mode (as shown in figure 6), we used three colors to mark different traffic capacity (green means passable; black means impassable; gray means uncertain). Traffic capacity map is useful in route planning for the urgent delivering of rescue team, relief supplies and victims. Moreover, the post-earthquake traffic flow control also needs this information.

![Figure 5. Bridges marked by damage levels.](image)

![Figure 6. Bridges marked by traffic capacity.](image)
5. Conclusions
In this paper, we investigated the rapid assessment method and software developing technique for traffic capacity of girder bridges after a major earthquake. To provide a highly applicable tool, which can assess the damage level and traffic capacity of girder bridges accurately and quickly, we proposed a new rapid assessment model for girder bridges, which contains a vulnerability model with parameter modification and a fast evaluation method for traffic capacity. Based on this model, we developed a rapid assessment software for girder bridges, using Visual C++ and ArcGIS Engine, in which the damage level and traffic capacity of girder bridges post-quake can be highlighted with colourful segments in the road network. Furthermore, we illustrated the functions and usages of this software through an application example.

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