

## Rapid structural safety evaluation system of expressway bridges under bulk transportation

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**Abstract.** In view of the increasing of heavy industrial equipment transportation on highway and the practical needs of the bridge safety assessment and consultation of heavy transportation, main characteristics of heavy transportation are firstly summarized. Then, the safety assessment criteria and rapid assessment method of the bridge structure regarding passage of large vehicles are studied and demonstrated via specific project examples. Finally, based on the proposed bridge structure safety assessment criteria and rapid assessment method, the bridge structure model library collected from main passages of highways is established. In addition, based on cloud service, the model library is integrated into a rapid safety assessment system of heavy-cargo transportation over bridge structures for realizing the informationization of safety assessment of bridges with heavy transportation, greatly shorten the approval procedure of highway heavy-cargo transportation, and facilitate the construction of major projects such as energy and equipment manufacturing.

**Keywords:** bulk transportation; equivalent load method; rapid evaluation system; bridge safety assessment.

### 1. Introduction

Highway transportation is characterized by the widest service range, the largest passenger and cargo turnover and the most flexible organization structure. As a special transportation field, heavy-cargo transportation is an important task in highway transportation [1]. In recent years, with the rapid development of society and economy and the in-depth implementation of the strategy of strengthening industries nationwide, large-scale key projects in metallurgy, petrochemical, water conservancy and electric power industries continue to be launched, and industrial equipment tends to develop in large and heavy scales. The transportation tasks of large equipment such as generator sets, transformers, oil storage tanks, large boilers and racks are becoming more and more heavy. Expressways have increasingly become the main carrier of large transportation services, and the transportation of large and heavy industrial equipment on expressways is becoming more and more frequent [2~4].

The objects of heavy-cargo transportation are usually very important and vulnerable, and they are of overweight, ultra-long, ultra-wide, ultra-high, high-value characteristics, and cannot be disintegrated [4]. The vehicle loads of large transporters are different from standard vehicles used for designing of bridge structures, which may exceed the design standards, threaten the safety and reduce the service life of bridge structures, thus exposing bridges to greater safety risks [5]. The "Notice from the General Office of the Ministry of Transport on Further Optimizing the Interprovincial Parallel Transportation Permit Service" issued by the Ministry of Transport requires optimization of the examination and approval process of the heavy-cargo transportation, the shortening of the examination and approval time, and the unification of the time limit for the issuance of transportation permit. However, at present, due to the lack of a professional system in most provinces for rapid assessment of the safety of bridge structures along the route relating to the required transportation, the efficiency is low, resulting in the current permit of heavy-cargo transportation being pressing, tedious, and of high risks.

Based on the above background, and combined with the rapid safety assessment of bridge structures demanded by Yunnan province, this paper addresses the rapid safety assessment of highway bridges undergoing heavy-cargo transportation, which aims at the informatization of heavy-cargo transportation management on highways in Yunnan province.

## 2. Main characteristics of heavy-cargo transportation

According to the Regulations on the Administration of Over-limit Transport Vehicles Driving on Highways (Order No. 62, Ministry of Transport of the Republic of China), heavy-cargo transport refers to the over-limit transport vehicles carrying non-disintegrable goods to transport goods through highways. Large transportation projects are significantly different from conventional highway traffic, which is mainly manifested in the following three aspects.

### 2.1 Bulk transport objects are usually very important and vulnerable goods

The bulky cargo is usually "overweight, extra long, extra wide, extra high, high value, non-disintegrable" important equipment, such as stators for hydropower stations, transformers for power stations, drill bits for shield machines for subways. The unit price of these equipment is tens of millions or even hundreds of millions of yuan. Transportation tasks of these key equipment are directly related to the cost, quality and schedule of construction of "large" projects. Once there is a delay or even an accident, the follow-up project will be difficult to continue, resulting in the rise of the cost of the whole project and affecting the smooth implementation of the key project. Therefore, large transportation projects have a high degree of importance and concerning, directly related to the implementation of major engineering projects. Therefore, this type of transportation is kind of "must", and absolutely not afford to any delay or damage.



Fig. 1 In transit is a transformer of Wudongde Hydropower Station in transit, a national major project of "West-East power Transmission"

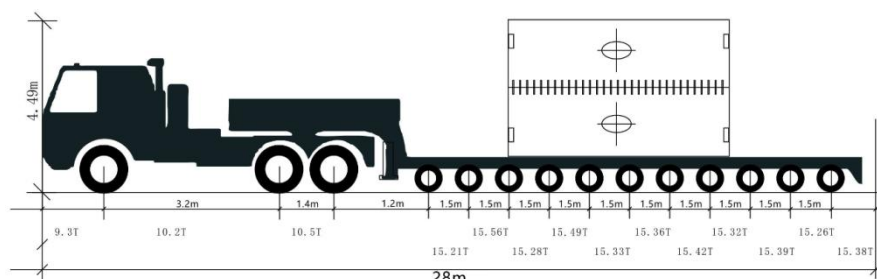


Fig. 2 Load layout of large transporter for transformer at Wudongde Hydropower Station

### 2.2 Tight schedule and heavy workload involved in safety justification of heavy-cargo transportation

To expedite heavy-cargo transport permits and benefit the construction of major domestic projects, the Ministry of Transport issued the Notice of the General Office of the Ministry of Transport on Further Optimizing the Interprovincial Parallel Transport Permit Service ([2018]

No.65) in 2018, proposing the need to optimize the approval management process of heavy-cargo transport, shorten the approval time, and unify the time limit for handling heavy-cargo transport permits. According to the notice, the maximum time limit for approval of heavy-cargo shipments should not exceed 20 working days.

Inter-provincial heavy-cargo transportations involve long distance highway travels, a large number of bridges along the line, of which the structural forms and technical status are complex, and the design standards are different. This situation complicated the safety assessment work. Taking the rapid bridge structural safety assessment of 180-ton-cargo transportation from Shuifu to Wuding completed by the author as an example, the project involved 11 high-speed highway segments with a total of 803 bridges. The design specifications of Bridges along the route adopted the General Specifications for Design of Highway Bridges and culverts in three different periods (1989, 2004, 2015). The assessment needs to classify and screen the bridges according to the declared transportation route, to consult and analyze the current technical status of the Bridges, and to analyze and calculate each structural type. Data collection and modeling are very large, time-consuming and laborious, and the efficiency is very low. When loading plans or routes change, they have to be re-evaluated, making it difficult to meet the 20-working-day limit required for approval.

### **2.3 Safety risks put on bridges under the action of heavy-cargo vehicles**

Bridges along the line would behave exceptionally under the heavy-cargo vehicles, of which the loadings are out of corresponding designing codes. It is likely to cause a large degree of reduction on the safety margin and service life of the affected highway bridge structures [5]. Bridges built in the early years are experiencing ongoing aging, and their technical conditions and carrying capacity have declined significantly. Once logistics enterprises lack the professional and technical knowledge of Bridges or "barbaric transportation" occurs in the actual transport process, it is likely to cause damage to the Bridges, or put them at risks of severe damage or even collapse. In turn, it could lead to serious economic losses and huge social impact.

## **3. Safety evaluation criteria and rapid evaluation method of bridge structures**

### **3.1 Basic Assumptions**

At present, there are two common methods for rapid assessment of the load-bearing capacity of Bridges for large transport vehicles at home and abroad, namely simplified discrimination by equivalent load and limit-state checking method of load-bearing capacity [6]. These two methods are carried out on the premise that the verified bridge meets the original design standards, that is, the load-bearing capacity does not decrease according to the original design specifications. According to the "Maintenance Code for Highway Bridges and Culverts" (JTG H11-2004)[7], the load-bearing capacity of Bridges with technical status indicators of Class 1 and Class 2 can meet the design index. Therefore, it is basically assumed that the technical status of Bridges is rated as Class 1 and Class 2 (for class 3 and below, the assessment shall be carried out after reinforcement).

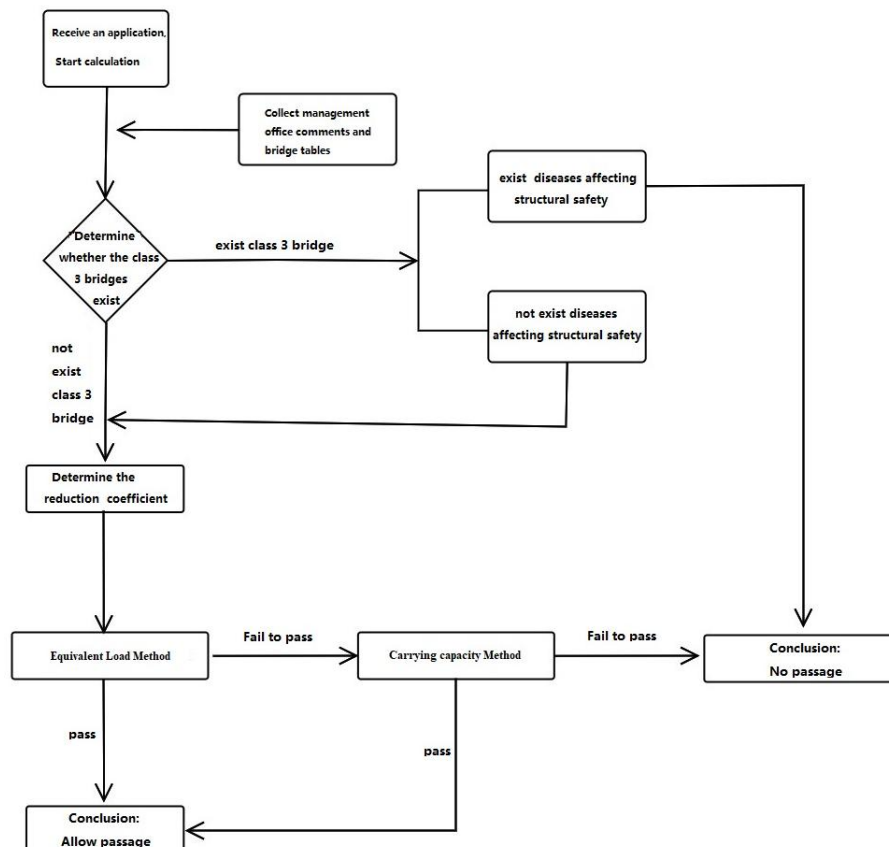


Fig. 3 Main process of heavy-cargo transportation evaluation

### 3.2 Criteria and rapid evaluation methods

(1) Simplified discrimination of equivalent load: The designing load effects and those of heavy-cargo transport vehicles are calculated respectively with the same influence line of the same structure, and the two are compared to determine whether vehicles can safely pass the bridge or whether bridges should be reinforced. For safety consideration, the load effects of the design load are not considering the impact coefficient, but only considering the combination coefficient of 1.4. According to the Maintenance Code for Highway Bridges and Culverts (JTG H11-2004)[7], Heavy vehicles pass in the most favorable way (driving along the center line to avoid eccentric load as far as possible, driving at a speed of less than 5km/h and keeping a uniform speed, avoiding braking force as far as possible). Therefore, when calculating the load effects of heavy vehicles, the coefficient of 1.0 times, and dead load and other variable loads are not included. The decision basis is shown in the figure as follows: when the load effects of the heavy-cargo transport vehicle are less than or equal to those of the design load, it is considered safe for the heavy-cargo transport vehicle passing through; When the load effects of the vehicle are greater than the designing ones, it is necessary to use the limit state checking method of the standard load-bearing capacity for further checking.

(2) Limit-state checking method: In accordance with the current design code for highway Bridges and culverts (Code for Design of Reinforced Concrete and Pre-stressed Concrete Bridges and culverts) (JTG 3362-2018) [8], the load-bearing capacity checking (strength, stiffness and stability) is carried out. Heavy-cargo transport vehicles are allowed to pass after the checking is passed. If the checking fails, corresponding structural strengthening should be carried out until the load-bearing capacity meets the requirements.

#### 4. Practical example of rapid safety assessment

The basic information of a heavy-cargo transportation project is that a transformer was transported by Sichuan Jetta Transportation Co., LTD. The total weight of the vehicle and cargo is 179t (including the weight of the tractor), the average axle weight of the vehicle plate is 15t, and the external size of the vehicle is 27×3×4.5 (m). The transport model is composed of 3 - axle tractor and gooseneck full hydraulic two longitudinal 10 - axle plate. Detailed load layout is shown in Figure 4.

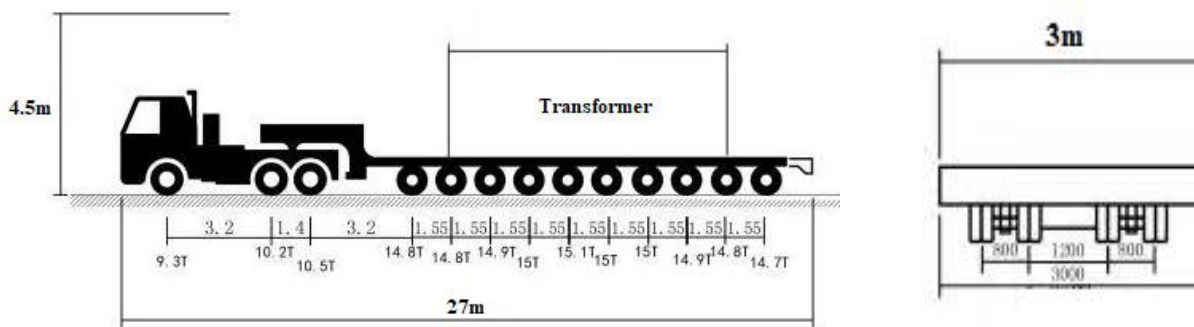


Fig. 4 Detailed load layout of a heavy-cargo transporter

##### 4.1 Examples of simplified discrimination of equivalent load

The simplified discriminant method of equivalent load is introduced with the example of 20 meters pre-stressed concrete continuous T beam with 2 holes on the high speed. According to the transverse connection of the bridge, the rigid plate beam method is used to calculate the transverse load distribution. Because the vehicles are supposed to locate in the center of the bridge deck, the transverse distribution coefficient of the side beam is very small when the vehicles pass, so only the middle beam is checked.

The transverse load-distribution coefficient of middle beams was calculated by Dr. Bridge software, and the calculation results are shown in Table 1.

Table 1. Transverse load-distribution coefficients

Position	coefficient value			
	Heavy-cargo transporter		Highway - Class I 2004	
Middle beam	$m_1$	0.339	$m_2$	0.623

The finite element analysis software Midas Civil 2021 was used to analyze and calculate the structure of 2-hole 20 meters pre-stressed concrete continuous T beams with plane bar element. The beam model was used to calculate, the main beam was simulated by beam element, and the boundary conditions were simulated according to the actual design situation. The results are compared between the heavy-cargo transporter and the original designing load (highway - Grade I 2004).

Under the load of heavy-cargo transporter (moving in the center of bridge deck), the bending moment and shear envelope of middle beam are shown in Figure 5 and Figure 6.

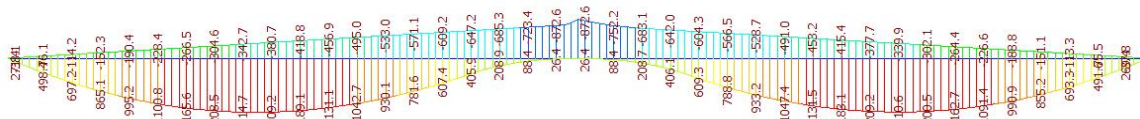


Fig. 5 Bending moment envelope diagram of middle beam under the action of heavy-cargo transporter (Unit: kN·m)

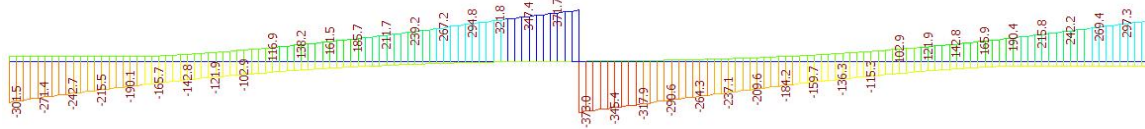


Fig. 6 Shear envelope diagram of middle beam under the action of heavy-cargo transporter (Unit: kN)

Under the original designing load of the bridge (highway - Grade I 2004), the bending moment and shear envelope of the middle beam are shown in Figure 7 and Figure 8:



Fig. 7 Bending moment envelope diagram of middle beam under the action of highway - Grade I 2004 (Unit: kN·m)

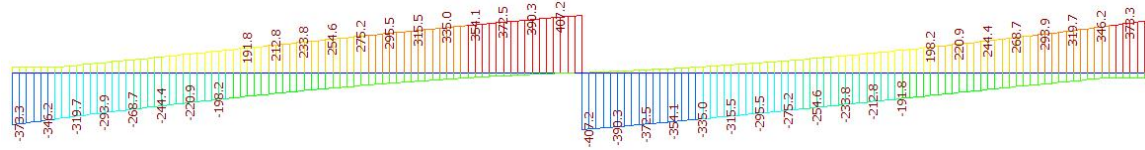


Fig. 8 Shear envelope diagram of middle beam under the action of highway - Grade I 2004 (Unit: kN)

It can be seen from Figure 5-8 that the load effects (bending moment and shear force) of the heavy-cargo transporter are lower than the designing load effects (highway - Grade I 2004), and safety margins are still large. Therefore, it can be determined that the heavy-cargo transporter can safely pass through the 2-hole 20-meter pre-stressed concrete T-beam from the perspective of structural stress level.

#### 4.2 Example of limit state checking by standard load-bearing capacity

Taking the 30-meter pre-stressed concrete simply supported T beam with one hole on the high speed as an example, the checking method of the limit state of equivalent standard bearing capacity is introduced. In the actual checking process, the simplified discriminant method of equivalent load is firstly used for calculation. The results show that the load effects of the heavy-cargo transport vehicle are higher than those of the designing load, so it is necessary to further enforce the limit state checking method of standard load-bearing capacity.

According to the transverse connection condition of the bridge, the rigid plate beam method is used to calculate the transverse load distribution. Because the vehicles are supposed in the center of the bridge deck, the transverse distribution coefficient of the side beam is very small when the heavy-cargo transport vehicles pass, so only the middle beam is checked.

The transverse distribution coefficient of middle beams was calculated by Dr. Bridge software, and the results are shown in Table 2.

Table 2. Transverse load-distribution coefficients

position	coefficient value					
	Heavy-cargo transporter		Steam over grade -20		Trailer - Level 120	
Middle beam	$m_1$	0.353	$m_2$	0.646	$m_3$	0.413

The finite element analysis software Midas Civil 2021 was used to analyze and calculate the structure of a 30-meter pre-stressed concrete simply supported T beam with 1 hole by using the plane bar element. The single beam model was used to calculate, the main beam was simulated by beam elements, and the boundary conditions were simulated according to the actual design situation.



According to the current Code for Design of Reinforced Concrete and Pre-stressed Concrete Bridges and Culverts for Highway (JTG 3362-2018), the flexure and shear bearing capacity was checked. The results were shown in Figs 9 and 10.

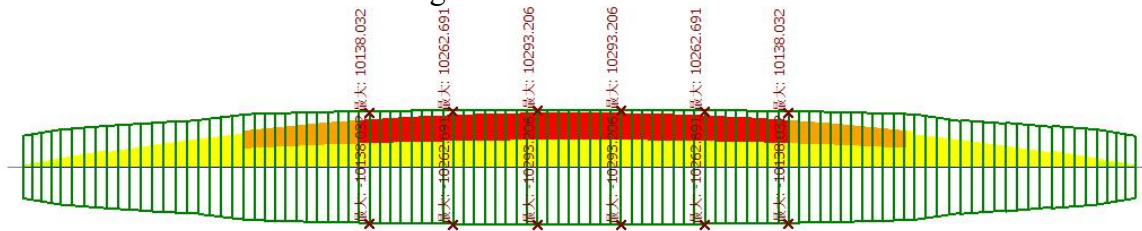


Fig. 9 Envelope diagram of flexural bearing capacity of middle beam (Unit:  $\text{kN}\cdot\text{m}$ )



Fig. 10 Envelope diagram of shear bearing capacity of middle beam (unit:  $\text{kN}$ )

As shown in Figs. 9 and 10, the maximum and minimum bending moments of the middle beam are within the envelope of flexure bearing capacity, and the maximum and minimum shear forces are within the envelope of shear bearing capacity, and the structural force meets the standard's requirements. Therefore, in terms of structural stress, the vehicle can safely pass through the bridge.

## 5. Development of rapid evaluation system for structural safety of heavy-cargo transportation Bridges based on cloud services

### 5.1 System construction objectives

With the normalization of application for approval of heavy-cargo transportation and the requirements to improve continuously highway service quality, the traditional working mode of "waiting and waiting" has been outdated in practical applications. Therefore, it is necessary to establish a rapid evaluation system based on cloud service for the safety of bridge structures due to heavy-cargo transportation, which integrates all the bridge structural models of the main high-speed channel, carries out a rapid, scientific and reliable evaluation for the safety of heavy-cargo transportation, provides complete sets of rapid and precise technical support for the approval and consultation of heavy-cargo transportation, and builds a heavy-cargo transportation service platform for the highways. Furthermore, it would help the construction of major projects such as energy and equipment manufacturing, so as to ensure the high quality completion of the highway transportation support task in the new era [9]. Figure 11 shows the rapid safety assessment system for heavy-cargo transport Bridges in Yunnan Province, which is currently under development.



Fig. 11 Heavy-cargo transport bridge structural safety assessment and consultation system

## 5.2 General system construction

The system construction adopts a cloud service mode. By deploying the checking analysis software and bridge analysis model in the cloud server, the distributed solution mode is established, which can realize the rapid checking of Bridges in batches under the action of heavy-cargo transportation loads and improve the evaluation efficiency. The overall technical flowchart of the system is shown in Figure 12.

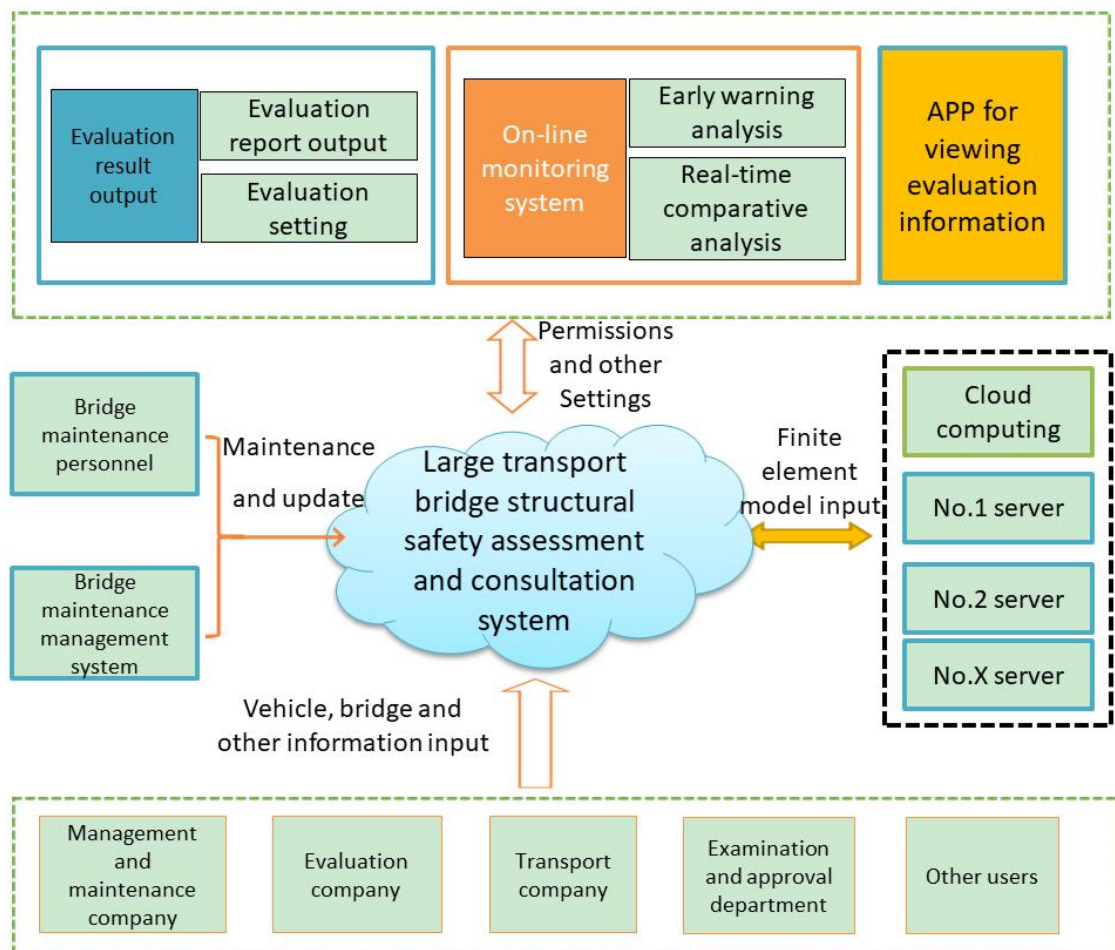


Fig. 12 Overall technical flowchart of the system



### 5.3 Application Scenarios of the System

The system is mainly used in three scenarios: routine maintenance, system use under heavy transportation loads, and personnel viewing from approved units. Daily maintenance is mainly to ensure the integrity of platform information and the timeliness of data information, so as not to spend more time on information updating and maintenance when it is necessary to evaluate the load of heavy-cargo transportation. The use of the system under the action of heavy-cargo transportation load mainly refers to the login system of the assessment personnel of the bridge evaluation undertaking unit, and the evaluation work is carried out according to the information of heavy-cargo transportation route and heavy-cargo vehicle load. Platform viewing is mainly used for non-system maintenance personnel and non-bridge evaluators to log in to view the current evaluation progress and download related evaluation reports.

### 5.4 Main contents of system development

To develop a cloud service-based safety assessment and consultation system for bridge structures undertaking heavy-cargo transportation tasks, and to carry out rapid structural safety assessment, the following six aspects of construction and research should be completed:

- (1) Build a computing platform based on cloud platform and local server to provide the basis for rapid evaluation;
- (2) Establish the structural model library of high-speed heavy-cargo transport Bridges;
- (3) Establish modules for input of heavy-cargo transport vehicles and dynamic updating of bridge details to realize rapid retrieval and sharing of information;
- (4) Establish an evaluation control module to support adjustment of key parameters in the evaluation of different regions and bridge types;
- (5) Construct an open evaluation method based on the finite element analysis software of bridge structure, realize the automatic distribution of analysis models and data storage;
- (6) Establish an automatic output module, quickly generate evaluation and analysis reports, and provide decision-making basis.

## 6. Conclusions and prospects

### 6.1 Conclusions

Transportation tasks of large and heavy industrial equipment on highways are becoming increasingly frequent. There is a practical need in authors' daily work to accomplish rapid evaluation of structural safety, by virtue of comprehensive consideration of safety evaluation criteria, simplified checking method of equivalent load and the limit state load-bearing capacity checking method. On the basis of the above mentioned bridge structure safety evaluation criteria and rapid evaluation method, the highway bridge structure model library is established, which is integrated into the rapid safety evaluation system of bridge structures undertaking heavy-cargo transportation tasks. In so doing, the informatization of highway heavy-cargo transportation related bridge safety evaluation is realized, which shortens significantly the consulting service time used in examination and approval.

### 6.2 Prospects

- (1) At present, the specifications differ drastically among heavy-cargo transport vehicles in China, parameters of which include axle weight, axle spacing and driving performance [10]. There is a lack of relevant standard guidelines. Parametric investigations are needed in the future in terms of the effects of vehicle parameters on the concerned bridge structures, and hence loading standards and guidelines of heavy-cargo transport vehicles can be formed, so as to guide the loading of heavy-cargo transport vehicles.

(2) At present, the axle load of the plate trailer can even reach 200kN when carrying out the transportation of overweight and large parts. The axle load of heavy-cargo transport vehicles is too high, so that the tensile stress developed inside the road surface is likely to exceed the allowable level, resulting in pavement damage [11~12]. However, at present, there is no software for quantitative analysis of this kind of damage. Therefore, it is impossible to evaluate the cost of pavement damage based on quantitative analysis, which is expected to be developed in the future.

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