Research on Key Problems and Strategies of Bridge Design of Meng'a Highway

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Abstract: There are many key problems to be solved in the design process of highway bridges in mountainous areas. In this paper, taking the design of Meng'a Highway bridge and culvert as the research object, the main key problems in the design process are as follows: the design of bridges crossing active faults, the seismic design of bridges and culverts in high seismic intensity areas, the design of bridges with high piers on slopes, the design of prefabricated bridges and the assessment of bridge safety risks, The corresponding solutions are put forward to provide reference for the design of highway bridges in mountainous areas.

Keywords: highway; bridge design; active fracture; seismic design; risk assessment

1. Introduction

The construction of highways is a favorable measure to promote the economic development of Southwest China [1-5]. However, most of Southwest China is mountainous area, so the combination of roads, bridges and tunnels can be used to reduce the project cost. There are many key problems to be solved in the design process of highway bridges in mountainous areas, such as bridge seismic, bridge super high pier construction technology, adverse geological conditions, bridge construction technology and risk assessment [6-12]. Based on the key problems existing in the bridge design of Meng'a Highway, this paper analyzes the problems faced in the bridge design of mountainous highway and the solutions.

2. Engineering Overview of Meng'a Highway

2.1. Geological Structure

Lancang- Menglian (Meng'a) Highway is an important part of the "15th link" (Mojiang-Pu'er–Lancang-Meng'a) highway in the 20th link of Yunnan Provincial Road Network Planning and Revision (2016-2030). The total length is 48.8 km, including 40 bridges with a total length of 15190 m. The highway is located in the Changning-Lancang fold belt in the South extension of Sanjiang fold system.

The route section is mainly located in the Menglian fold bundle, with more anticlines than synclines. Along the syncline axis, it is mostly replaced by faults. It is often an inverted anticline near the major fault zone.

2.2. Earthquake

The route area has frequent earthquakes. There have been six records of seismic activities with $m \geq 5$ in the area where the route passes, and the seismic intensity is generally 7-8 degrees. According to the Seismic Ground Motion Parameter Zonation Map of China (GB18306-2015) and the Seismic Peak Acceleration and Response Spectrum Characteristic Period Zonation Map of Yunnan Province, the design basic seismic acceleration response characteristic period of the project is 0.45 s, the seismic peak acceleration is 0.4 g, and the corresponding seismic intensity is IX degree. The earthquake has a great impact on the bridge, culvert, tunnel and other structural structures of the project. In the design, targeted measures should be taken to do a good job in seismic design.

2.3. Hydrogeological Conditions

There are rivers and gullies distributed along the line with extremely complex groundwater type and water yield, which can be used for construction. The water quality is good, and there is no corrosion micro corrosion to engineering structures, which can meet the needs of engineering construction.

The rock and soil distributed in the area are mainly soft rock group or extremely soft rock group, with low hardness, poor cohesion, weak erosion resistance and weathering resistance, and poor stability. Under the joint action of the above two factors, the stability of rock and soil mass in the area is poor, which is prone to geological disasters such as landslide and collapse.

In the project area, adverse geological process and special rock and soil are relatively developed, and landslide, potential unstable slope, strong earthquake area, earthquake liquefaction, karst, dangerous rock, collapse and rock pile, goaf, bedding slope, soft soil, red clay, etc. are all developed. The main unfavorable geology and special rock and soil that have great influence on the route are strong earthquake area, earthquake liquefaction, landslide, unstable slope, dangerous rock and collapse, karst, slope soft soil, etc. In addition, the strata in the route area are mostly mudstone, shale and other soft rock strata

According to different types of unfavorable geology and special rock and soil, avoidance and corresponding engineering measures should be taken in the design.

3. Analysis of Key Problems and Countermeasures

3.1. Bridge Design across Active Faults

The project crosses Menglian fault, which is Holocene Active fault. In order to ensure the safety of bridge structure crossing active fault, the solutions are as follows:

(1) On the basis of the engineering geological structure survey, the activity and geological conditions of the fault structure are comprehensively evaluated, and the bridge is built in the seismic favorable section as far as possible. If the bridge is unable to avoid the active fault, the narrow position of the fracture zone should be selected. If the bridge is parallel to the seismogenic fracture zone, it should be placed at the footwall of the fracture zone. At the same time, the corresponding repair plan and guarantee plan are formulated to deal with the situation that the bridge across the fault is damaged due to the sudden earthquake.

(2) According to the seismic safety evaluation, determine the longitudinal and transverse accumulated displacement of the bridge beam caused by the influence of the fault zone activity, lengthen and widen the cover beam of the lower pier according to the displacement, increase the support width of the main beam, reserve space with elastic materials, and set secondary pad stone and block. Adopt the measures of reducing and isolating earthquake, such as reducing and isolating bearings and viscous dampers; strengthen the measures of preventing falling of beams, such as setting coupling beam device, cable limit device, strengthening the setting of anti-seismic blocks, etc.

(3) Small span simply supported structure or structure simply supported bridge deck continuous structure shall be used for bridges crossing faults and nearby faults. Steel beams or steel-concrete composite beams with light self weight and small seismic force shall be used as main beams. Spare steel beams or quick assembling Bailey beams shall be set near the bridge site for quick repair and replacement of main beams. The advantages of steel box girder or steel-concrete composite girder compared with reinforced concrete girder are: light self weight, which can reduce the seismic inertia force; good ductility, which is not prone to brittle failure; good deformation coordination, which can still be in the elastic deformation stage after large deformation, without fracture, which can better maintain the bridge performance.

(4) The pier with higher risk level shall be set at the footwall of active fault, and the pier with larger shear and torsional rigidity shall be adopted to resist the larger shear and torque caused by fault displacement, so as to avoid the inclination or damage of pier post earthquake.

(5) Install bridge health operation sensors and transmit them to computer network in real time to establish bridge pier displacement identification and early warning processing and facilitate remote diagnosis and analysis.

3.2. Seismic Design of Bridges and Culverts in High Seismic Intensity Area

In this project, the peak value of seismic peak acceleration of K0 + 000 - K7 + 000 section is 0.4g, and the corresponding seismic intensity is IX degree; the end point section of K7 + 000 - K48 + 800 is 0.3g, and the corresponding seismic intensity is VIII degree. In order to ensure the safety of bridge structures along the line, the following measures are proposed:

(1) According to the seismic safety evaluation, the bridge site shall be hard and stable as far as possible, and pay attention to the natural vibration characteristics of the structure and foundation to avoid the influence of resonance; on the soft foundation, pay attention to the integrity of the foundation to prevent the uneven deformation caused by the earthquake.

(2) The upper structure of the bridge adopts continuous structure to prevent the collapse of structural and non structural components during earthquake. The structural layout shall be uniform, symmetrical and regular in geometric dimension, mass and rigidity, and avoid sudden change.

(3) Improve the overall strength and ductility, make the structure suitable without increasing the weight and changing the stiffness.

(4) Extend the vibration period of the structure, consume the seismic energy, reduce the displacement of the structure, and ultimately reduce the dynamic response of the structure by using the isolation support, damping and energy dissipation devices.

(5) Pay attention to the seismic design of the foundation itself, especially for the pile foundation, so as to avoid the damage of the bridge structure caused by the foundation damage.

(6) For bridges in strong earthquake area, the design concept of multiple lines of defense, graded damage is adopted. During the design, local components that are easy to repair can be sacrificed to ensure the safety of the overall structure of the bridge.

3.3. Design of High Pier Bridge on Slope

The project has high mountains, deep ditches and high proportion of bridges and tunnels. There are many high pier bridges, some of which are more than 60 meters high. Therefore, how to design high pier bridges and ensure the safety, economy and feasibility of the structure is the key to the bridge design of this project.

We must pay attention to the concept design of bridge structure. Considering the seismic performance of high piers from the beginning of structural selection, reasonable structural form and successful seismic design can greatly reduce or even avoid the occurrence of seismic damage. In recent years, it is found in the summary of earthquake disaster experience that conceptual design is more important than computational design for the seismic design of structures. In combination with the actual situation of the project, the following problems should be paid attention to for the anti-seismic of high piers:

(1) The bridge in mountainous area is generally located on the horizontal curve, and the radius of some horizontal curves is relatively small. However, the seismic response of the bridge pier on the horizontal curve has obvious coupling phenomenon of bending and torsion. Therefore, it is better to adopt the pier section with larger torsional rigidity in the seismic area.

(2) When the pier is relatively high, the stiffness of the whole bridge is relatively small, its natural frequency is small, and the vibration mode is mainly horizontal horizontal vibration, and its transverse stiffness is often relatively small, which should be paid attention to. It is better to increase the transverse rigidity of the bridge pier by some measures.

(3) Under the action of earthquake, the integrity of pier structure is very important. Therefore, try to use some pier types with good integrity, such as hollow thin-walled pier.

(4) For the integral subgrade section, if the cross slope of the ground is steep, the bridge shall be arranged with staggered holes to avoid the excavation of adjacent piers on the left and right sides, so as to void the pile foundation on the side of short piers.

3.4. Fabricated Bridge Design

In China, infrastructure construction has been vigorously carried out, and the concept of sustainable development has been put forward. In the process of bridge construction, more attention has been paid to the coordination with the environment. More and more attention has been paid to the efficient construction methods of energy conservation, environmental protection and assembly. At the same time, prefabricated rapid construction method also shows the advantages of easy quality control, easy time control, eco-friendly and so on.

Prefabricated bridge with prefabricated erection, simple support and continuous structure is a common bridge type of medium span bridge with good economy. By adjusting the cantilever length and the continuous end length of pier top, it can well adapt to the characteristics of multiple bends and small radius of the project. The following points shall be paid attention to in the design:

(1) Based on the popularization experience of Mountainous Highway in recent years and the construction conditions, technical experience and equipment storage status of Yunnan Province, the prefabricated T-shaped continuous beam (prefabricated beam simple support first, then structure continuous) or prefabricated prestressed small box beam (prefabricated beam simple support first, then structure continuous) structure shall be adopted as far as possible for the superstructure of the bridge in this section, so as to ensure the deck leveling and driving through structure continuous comfortable. As far as possible, common reinforced concrete cast-in-place or thin-walled piers with uniform structure and size shall be adopted for the substructure, and bored single pile or pile cap group foundation shall be adopted.

(2) Pay attention to the selection of the height span ratio of the bridge, and try to use the most economical span height ratio when there is no special requirement.

(3) In the design of bridge and culvert, the requirements of objective construction conditions, construction technology and construction period shall be fully considered to avoid the disconnection between design and construction.

3.5. Bridge Safety Risk Assessment

The terrain of the proposed route is deeply cut and passes through the valley and steep slope among mountains for many times. A large number of high pier bridges, super large bridges and steel box bridges have certain construction safety risks in the construction stage. In order to avoid serious and extra large production safety accidents, reduce casualties and economic losses, and ensure the safety of highway engineering construction. Bridge safety risk assessment shall be conducted for the project.

(1) Strengthen data collection and communication for typical bridges, and fully collect relevant design and construction organization data. According to the geological conditions, natural environment conditions and construction organization status of the project location, and in accordance with relevant national standards and industry standards, identify the risk sources in the construction process.

(2) Organize competent bridge experts of the Institute to determine the main risk sources in unit works, divisional works and subdivisional works in combination with the actual geological conditions and environmental conditions of the project. According to the risk index system method recommended in the guide, the risk assessment is carried out.

(3) According to the estimated safety risk level and risk acceptance criteria, risk control measures are proposed from the aspects of safety management measures and safety technical measures on the project site.

4. Conclusions

Taking Meng'a Highway as the research object, this paper sums up the main key problems existing in the design of highway bridges in southwest mountainous areas, and analyzes the main solutions. The main research conclusions are as follows:

1. Bridge design across active faults, bridge and culvert seismic design in high seismic intensity area, slope and high pier bridge design, assembly bridge design and bridge design Safety risk assessment is the key problem in the bridge design of Meng'a Highway.

2. In the design of highway bridges in mountainous areas, proper bridge site, bridge type, bridge structure and materials should be selected, and the risk sources existing in the construction process should be effectively identified to achieve the purpose of safety and economy.

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