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Cable-Stayed Railroad Bridges

Ponts ferroviaires à haubans

Eisenbahn-Schrägseilbrücken

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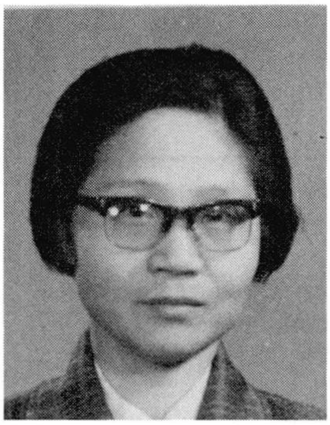

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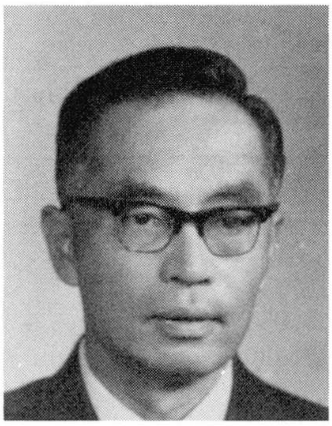

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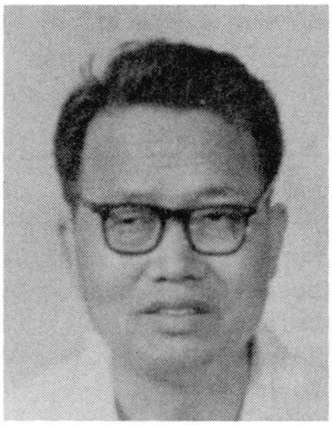

SUMMARY

This paper presents some research results for cable-stayed railroad bridges for the structural system, economical analysis and effects of braking action, thermal forces, dynamic behaviour etc. Suggestions for design and construction are also given.

RESUME

Le présent article donne des résultats de recherches sur les ponts ferroviaires à haubans: système structural, analyse économique, effets des forces de freinage, des forces thermiques, comportement dynamique etc. Des suggestions pour le projet et la construction sont présentées.

ZUSAMMENFASSUNG

Dieser Beitrag stellt Forschungsergebnisse für Eisenbahn-Schrägseilbrücken vor: Konstruktionssysteme, Wirtschaftlichkeitsuntersuchungen, Einflüsse von Bremskräften und Temperaturänderungen sowie zum dynamischen Verhalten von Schrägseilbrücken. Anschliessend werden Anregungen für Projektierung und Ausführung gegeben.

1. INTRODUCTION

It is still a controversy today that can the cable-stayed bridge be also used for railroad.In fact,early in 1960's some of railroad bridges,like North Romaine River Bridge in Canada and Neckarbrucke Bridge in Germany,had parts of their members made of cables.Among cable-stayed railroad bridges built since late 1970's to early 1980's,the Hongshui River Bridge--a prestressed concrete cable-stayed railroad bridge for single track with 96 m main span in China (Fig.1) and the Save River Bridge--a steel cable-stayed railroad bridge for double track with 254 m main span in Yugoslavia were two notable achievements during that period.

As far as railway/highway combined bridge is concerned,the main span of Buenos Aires Parana River Bridge built in Argentina,1978,had reached 330 m and this record has been renewed to 420 m by Hitsushijima and Iwagurujima Bridges in Japan,1988. Until now the total number of cable-stayed bridges in the world which subjected to railway loads has exceeded 15 (Tab.1).

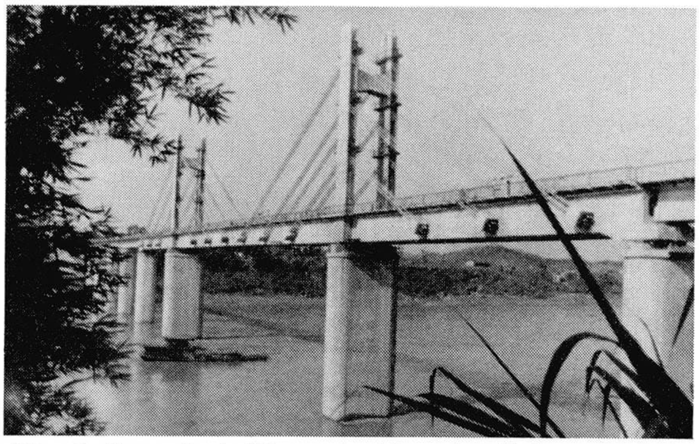

Fig.1 Hongshui River bridge in China

NAME OF BRIDGE	COUNTRY	SPAN(m)	TRACK	LANE	MATERIAL	YEAR
North Romaine Bdg.	Canada	61	1		steel	1960
Neckarbrucke Bdg.	Germany	77	1		concrete & steel	1966
Bridge of Isles	Canada	105	1	6	steel(concrete deck)	1967
Mainbrucke	Germany	148	1	6	concrete	1972
Zurhoff Bdg.	Netherland	100	2		steel	1976
Parana Bdg.**	Argentina	330	1	4	steel(concrete deck)	1977
Lyne Bdg.	Britain	59.3	2		concrete	1979
Omotogawa Bdg.	Japan	85	1*		concrete	1979
Save Bdg.	Yugoslavia	254	2		steel	1979
Posadas Bdg.	Argentina	330	1	2	concrete	1986
Hongshui R.Bdg.	China	96	1		concrete	1981
Hitsushijima Bdg.	Japan	420	4	4	steel	1988
Iwagurujima Bdg.	Japan	420	4	4	steel	1988
Caroni Bdg.	Venezuela	280				

Table 1. Cable-Stayed Railroad Bridges in the world
*--narrow gage track **--two bridges

According to the above mentioned practices,it is clear that cable-stayed railroad bridge has bright prospects.In this paper attempt is made to present some research results and to discuss design contemplations of cable-stayed railroad bridge with main span above 300m.

2. GENERAL ARRANGEMENT

According to the investigations made in China Academy of Railway Sciences (CARS)[2],nearly all types of cable-stayed highway bridge structures can be used for railroad.However,the optimal ratios of side span over main span (L1/L) and tower height over main span (H/L) are somewhat different due to the different ratios between live and total loads, LL/(LL+LD). It has been found that the economical tower height for cable-stayed railroad bridge with concrete tower and steel girder of span around 400 m is between 0.24L to 0.28L(Fig.2). And the recommended ratio of L1/L is not greater than 0.425.It has also been shown by analysis that the stresses and deformations in different parts of the bridge especially in side spans and towers could be reduced significantly if auxiliary piers should be placed in side spans.For a bridge like the one mentioned above one auxiliary pier in the middle of each side span would be enough.

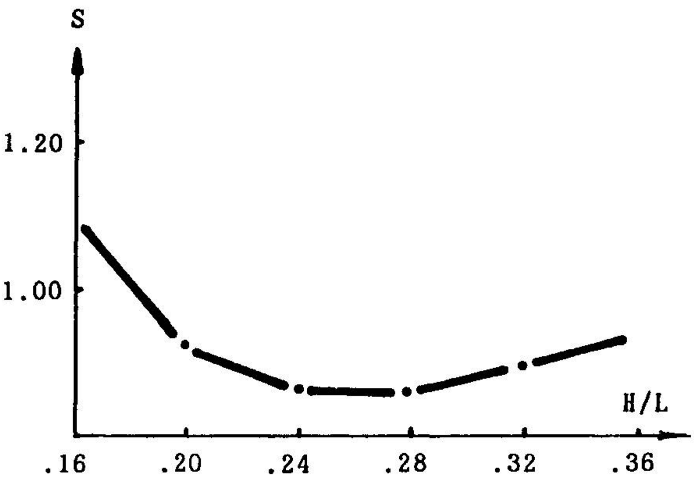

Fig.2 Cost of superstructure versus H/L

3. SUPPORTING SYSTEM

The principle of vertical supports arrangement for cable-stayed railroad bridge is almost the same as for highway one.For instance,between main girder and tower there is no need to fix rigid supports,which could cause remarkable changes of internal forces in the main girder.However,longitudinal supports are definitely needed for this kind of bridge.The results of analyses have indicated that, if there is no longitudinal support,not only large longitudinal girder displacement of cable-stayed bridge will occur under vertical loads, but also tremendous moment increases will take place in towers and piers when braking the train,for the braking forces have to be transferred to the foundations by cables through the upper part of the tower,enlarging the force arms (Tab.2).Besides,unfavorable longitudinal swaying and colliding of whole superstructure will happen in this case .It is clear that between superstructure and substructure of cable-stayed railroad bridge,longitudinal supporting system should not be neglected in order to transfer the braking forces and limit the longitudinal girder displacement. The more the longitudinal supports are provided,the better the forces in that direction will be distributed.

SUPPORTIING SYSTEM	SIDE SPAN MOMENT	MAIN SPAN MOMENT	AXIAL GIRDER FORCE	TOWER MOMENT	PIER MOMENT
without longitudinal supports	10730	0	40	87330	99720
with longitudinal supports	10	0	40	10	13040

Table 2. Effects of braking forces on cable stayed bridge with different supporting system (KN-M)

However,additional forces will be induced in a cable-stayed bridge with longitudinal supports and continuous deck when temperature changes.If there is only one longitudinal support ,attention should be paied to the fact that asymmetrical longitudinal support would cause non-symmetrical stress conditions in towers and piers.In case two or more rigid longitudinal supports are provided,considerable thermal bending moments and axial forces will occur respectively at the bottoms of piers and at the midspan of the girder when variation of the system temperature of the bridge takes place(Tab.3).Therefore,if viewing from the point of thermal effects only,the optimum alternative is the one where no longitudinal support is provided.Here we found opposite requirements to the cable-stayed railroad structure for undertaking brake forces and temperature variations respectively. In order to avoid this contradiction,it is needed to design a kind of special longitudinal support which can not only transfer the horizontal forces of train braking,but also accommodate the slow deformations of the structure when temperature changes.Hydraulic buffers or similar devices are desirable for this purpose.

SUPPORTIING SYSTEM	SIDE SPAN MOMENT	MAIN SPAN MOMENT	AXIAL GIRDER FORCE	TOWER MOMENT	PIER MOMENT
without longitudinal supports	18730	18470	870	58320	66550
with longitudinnal supports	13690	25240	33040	51990	349560

Table 3. Thermal forces of cable stayed railroad bridge with different supporting system (KN-M)

4.STRUCTURAL STIFFNESS AND FATIGUE

With regard to the heavy live load,the structural stiffness of cable-stayed railroad bridge should be larger than those for highway one in order to ensure the normal passing of vehicle.For this kind of bridge,the stiffness of the integrative structure is mainly depending on the stiffness of the girder,which basically varies with the girder depth,and on the stiffnesses of cables,which are mainly determined by their section areas.Apparently,if only the structural stiffness had to be considered,there could be many stiffness selections of girder and cables.However,the maximum stress in cables will exceed the allowable value if the girder is too strong and the cables are too weak,or on the contrary, severe nonlinear effects will take place due to low initial cable stresses if the girder is too slender and the cable areas are too large.

In order to avoid all these undesirable situations,a proper ratio between girder and cable stiffnesses should be chosen.A range of this ratio, defined by sum of cable stiffnesses over girder stiffness in the vertical direction [4], from $0.5*10^{4}$ to $1.5*10^{4}$ is recommended for cable-stayed railroad bridge with span around 400 m.

In design practice,fatigue stresses of cable or girder may become a controlling factor and this problem could usually be tackled by means of increasing the dead load appropriately.That is why concrete girder or steel girder with concrete deck is prefered for superstructure of cable-stayed railroad bridge.Ballasting the bridge deck can both facilitate the levelling work of track and reduce the

LL/(LL+LD) ratio.When it is possible,an ideal solution may be reached by adopting a railway/highway combined structure to improve the load ratio.

5. INITIAL CABLE FORCES AND UPLIFT FORCES

With cable-stayed highway bridge,the initial cable forces are conventionally determined according to the principle of rigid support continuous beam,i.e.the vertical component of initial cable force is equal to the vertical reaction force of relevant continuous beam.For cable-stayed railroad bridge,more economical design would be made if the initial cable forces could be increased to some extent, because higher initial cable forces can both improve the fatigue behaviour of cables and produce prestressed forces which act oppositely to the live load and therefore reduce the internal forces and deformations in the main girder under live loads. Nevertheless, in case of cable-stayed concrete bridge,attention should be paid to the time-depending deformations and forces induced by this initial cable force increasing.The desirable internal forces created by initial cable forces should have opposite signs to and half the magnitude of those caused by live loads.

For cable-stayed railroad bridge,filling weight and vertical anchor cables are usually needed to balancing the large uplift forces in side supports due to heavy live load.The uplift forces could be reduced if we use concrete for side span girder and steel for main span girder.In this case,special care should be taken with the detail of the joint which links the side span and the main span.The another way to deal with this problem is to make side span continuous into the approach span,which is also good for smooth angular changes at the end of the bridge.

6. DYNAMIC EFFECTS

It has been proved by practice that the dynamic effects of railway load on cable-stayed bridge are much larger than those of highway load.Beside the heavy, fast moving features of the load, the rhythm in track and vehicle structures also plays an important role in enhancing the dynamic response of bridge-vehicle system.The dynamic behaviour of the bridge influences not only the strength and safety of bridge structure itself,but also on the safety of vehicle and goods as well as passenger comfort.

The results of field test with Hongshui River Cable-stayed Railroad Bridge have indicated that the vertical vibration amplitude at midspan which reached 15% of the live load deflection and the dynamic stresses in outer cables which reached 28% of the live load stresses are the most sensitive ones among all dynamic deformations and stresses (Fig.3)[1].It has been shown by experimental and theoretical analyses that the dynamic effects will be enlarged if the vehicle speed increases and the most serious response will take place not at the time when

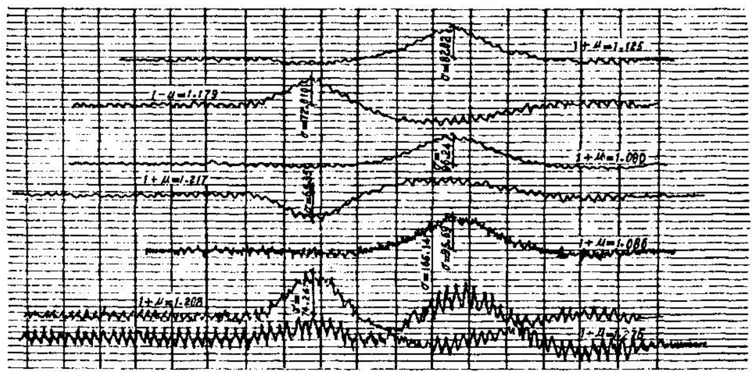

Fig.3 Dynamic testing results of Hongshui River Bridge

the whole train has entered the bridge but at the time when only a part of the train has entered the bridge,for the total mass and the dynamic behaviour of the whole vehicle-bridge system is changing when the train is moving[5].

It has also been revealed by theoretical analysis that the lateral vibrations of cable-stayed railroad bridge caused by moving vehicles are most sensitive to track irregularities in cross-level [2],so the track leveling work should be carried out very carefully for this kind of bridge.In addition,it is advisable to install damping devices at appropriate locations for reducing undesirable lateral oscillation of the superstructure under vehicle nosing forces and/or gusts.

The cross sections of railroad bridge girders are characterized by large depth versus small width which is unfavorable for aerodynamic stability.However this can be compensated by high torsional stiffnesses of the sections due to their strong lateral connections which enhance the torsion bending frequency ratio and consequently the critical wind velocity of the bridge.It has been found that for a double track cable-stayed railroad bridge of steel box girder with main span around 400 m,no danger from wind induced oscillation will be encountered.

7. CONCLUSIONS

The following points may be useful to cable-stayed railroad bridge designers:

1). It is not advisable to take any L1/L ratio greater than 0.425 and any tower height less than 0.24L or greater than 0.28L.A longitudinal supporting system which can both transfer braking forces and accommodate temperature variations is needed.

2). The suggested cable-girder stiffness ratio is between $0.5*10^4$ and $1.5*10^4$and a proper increase of dead load is encouraged in some cases to deal with the fatigue problem.It is desirable to have higher initial cable forces and heavier side spans to resist the railway loads.

3). Special attention should be paied to diminishing track irregularities in order to reduce the vehicle-bridge dynamic responces,and no danger will be encountered in aerodynamic stability for double track cable-stayed railroad bridge with box girder of span around 400 m.

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