Applied design codes on international long-span bridge projects in Asia

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ABSTRACT: Application state of design codes being utilized for international long-span bridge design projects in Asian region, in cooperation with Japanese consultant firms, is to be introduced in order to clarify several issues directly impacting on design methodology. Additionally noteworthy considerations are also to be described to resolve such the issues so that rational and compatible design thoughts will be applied to such the mega-strictures.

1 INTRODUCTION

1.1 Background

Recently, the economic power including the improvement of infrastructures in most of Asian developing countries has remarkably developed. Current the worldwide finance crisis certainly influences their economic growth; nevertheless, the potential capabilities for further development still would not decline. Although in former days, most of such the developing countries entirely depended upon financial and technical aids from major advanced countries for international long-span bridge construction projects (“the Projects”), current several the Projects, particularly in Korea and China, are being executed by their own engineered technical accumulation based upon their national budgets; however, for the technical field relevant to steel and composite structures, most of such the developing countries have still few accumulations of related studies and engineered technical experiences; the design codes or technical specifications have not been compiled comprehensively. Accordingly, multiple the design codes compiled in different countries are being collectively applied to the Projects; hence, various technical irrationalities between engineered considerations and fundamental design concepts would occur in several significant the Project. Therefore, the bridge engineers cannot but rationally apply multiple the design codes evaluating each design concept and methodology based upon their accurate engineered considerations.

In this report, several bridge types and application of the design codes relevant to steel or composite structures utilized in such the Projects in cooperation with Japanese consultant firms are to be introduced. Additionally noteworthy considerations for the applicability are also to be described in order to clarify several issues of current application of the design codes utilized in such the Projects.

2 APPLICATION OF DESIGN CODES UTILIZED IN INTERNATIONAL BRIDGE CONSTRUCTION PROJECT IN ASIAN REGION

2.1 Application of Design Codes in the Republic of Korea

2.1.1 Recent Technical Cooperation of Japanese Consultant Firms

The technical field relevant to steel and composite structures in Korea is significantly influenced by the design concepts specified in Japan and the U.S. The Specifications for Highway Bridges compiled by Japan Road Association (“JSHB”), the Design Standards of Superstructures for Long-Span Bridges compiled by Honshu-Shikoku Bridge Authority (“JDSS”) and the American Association of State Highway and Transportation Officials (“AASHTO LRFD”) are widely incorporated into the Korean Bridge Highway Design Code (“KBDC”). Particularly for steel structures, allowable stress design method is applied based upon JSHB and JDSS; for concrete or composite structures, their design concepts specified in AASHTO and the Euro Code (“Euro Code”) are fundamentally incorporated based upon load factor design method.

Recent the Project in technical cooperation with Japanese consultant firms are mainly for constructions of long-span cable supported bridges, in which various technical advices such as preliminary design, basic de-
sign, detail design and construction supervision have been provided. Recent the contract method is not eco-
nomic aids provided by the government of Japan but the direct contract such as design-build contracting
method between Japanese consultant firms and Korean relevant organizations.

2.1.2 Current International Project in Cooperation with Japanese Consultant Firms

The largest current the Project in cooperation with Japanese consultant firms is for the construction of Second
Incheon Bridge shown in Figure 1. The bridge will be located on the secondary access highway connecting
Yongjong Island, on which the Incheon international airport is located, to Songdo New City. The centre span
length reaches 800m, which will be the third longest span of existing the cable-stayed bridges in the world.
The bridge components were designed applying AASHTO LRFD (3rd Edition 2004) on the basis of limit de-
sign state method. Each the steel and composite section was determined based upon several critical cases of
load combinations resulted in comparing evaluations between KBDC and AASHTO LRFD; however, the
Japanese design codes such as JSHB and JDSS were not applied. The reasons why KBDC and the Japanese
design codes were not entirely applied to the design were that rational design concepts were required based
upon the limit state design method, and that technical intention of a British investing company that was a
business owner of this PFI project.

![Figure 1: General Drawing of Second Incheon Bridge.](image)

2.1.3 Section Forces Calculated in the Design Stage

The section forces were calculated under various load combinations specified in AASHTO LRFD and KBDC,
corresponding to several the limit states: i) Serviceability limit state, ii) Ultimate limit state iii) Accidental
limit state. The temporary steel structures to be installed in erection stage were designed based upon allow-
able stress design method.

The section sizes of most of the bridge components such as cables, steel deck and girders were determined
under specific load combinations including live loads. The comparison of live loads specified in KBDC,
AASHTO LRFD and JDSS is shown in the following Table 1., in which the strength of the live loads speci-
fied in KBDC is comparatively larger than those of AASHTO LRFD and JDSS. Generally, structural safety
of an entire bridge based upon a comparison of just only the load strength should not be estimated essentially
because the monolithic combination of load strength, load factors and design concepts would form an essen-
tial design system; otherwise, the strength of distribution of the live loads, specified in KBDC and indicated
in the table as DL, is obviously the largest of the other design codes in the table. Distribution loads ordinary
would become a dominant excitation.

<table>
<thead>
<tr>
<th>Live loads</th>
<th>KBDC</th>
<th>AASHTO LRFD</th>
<th>JDSS</th>
</tr>
</thead>
<tbody>
<tr>
<td>DL=75.00 KN/m</td>
<td></td>
<td>DL=48.36 KN/m</td>
<td>DL=46.85 KN/m</td>
</tr>
<tr>
<td>CL=918 KN</td>
<td></td>
<td>CL=1690 KN</td>
<td>CL=2154 KN</td>
</tr>
<tr>
<td>Reduction factor:</td>
<td>The number of lanes:0.75</td>
<td>The number of lanes:0.55</td>
<td>The bridge length:0.87</td>
</tr>
<tr>
<td>Wheel loads</td>
<td>188 KN/axle</td>
<td>145 KN/axle</td>
<td>200 KN/axle</td>
</tr>
</tbody>
</table>

2.1.4 Consideration on Design Methodology of Long-Span Bridge Applying AASHTO LRFD

This bridge would be an uncommon example of long-span cable supported bridge applying AASHTO LRFD.
Because large number of composite I-beam girder bridges has been constructed in the U.S. as the standard
steel bridge type, the specifications relevant to compressed stiffeners would be insufficient for designing them
appropriately. AASHTO LRFD specifies the limited compressive strength and the required size of such the stiffeners based upon those of infinite length; hence, applying the methodology to the finite compressed stiffeners would not be rational. Therefore, the compressed flanges and webs were verified based upon FHWA-80-205, in which ultimate strength are schematised on the basis of experimental or analysed results approached from various specimens of columns.

For horizontal stiffeners on girders, the minimum thickness of base plates requisite for installing the horizontal stiffeners is specified to be determined by the ratio of the thickness and the height of the base plates: \(D/t_w<150\); meanwhile, the ascension of the strength caused by the reinforcement utilizing such the horizontal stiffeners is not considered. Accordingly, the steel girders designed by AASHTO LRFD, on which the horizontal stiffeners are installed, would become irrational structures because spacing of vertical stiffeners would be obviously narrower in comparison with a design case utilizing KBDC. Nevertheless, the reduction of the ultimate shear strength based upon the parameterised stiffness of the vertical stiffeners is required in the case of applying the thin web plate given by using the foregoing equation such as \(D/t_w>150\). Moreover, double layer installation of the horizontal stiffeners is not specifically allowed.

As mentioned above, various methodological irrationalities between bridge engineer’s demands and design methodology would occur in the detail design stage because of differences of design concepts. Therefore, the bridge engineers must design rationally apply multiple the design codes evaluating each the design concept and methodology based upon their accurate engineered considerations and demands.

2.2 Application of Design Codes in the People’s Republic of China

2.2.1 Recent Technical Cooperation of Japanese Consultant Firms

Recent the Projects in technical cooperation with Japanese consultant firms are mainly for long-span suspension bridge projects. Current Chinese bridge engineers have efficient experiences of designing and constructing large number of domestic steel bridges including several long-span suspension bridges erected across Changjiang River; accordingly, they have efficient confidence with engineered capabilities based upon such accumulation of the experiences. The Projects including planning, computer analysis, designing, fabrication, manufacturing and construction would be comprehensively accomplished appropriately by their own-engineered capabilities. In particular, the designing based upon numerical computerized analysis resulted from rather highly-analysis methodology, using commercialised general software, is being performed in consideration of various design methodology incorporated from foreign design codes.

The opportunities for forwarding orders of the design to foreign consultant firms are currently being decreased; meanwhile, the independent check on the results performed by Chinese design firms are current major technical cooperation by the foreign consultant firms, such as verification of detailed design, technical advices for fabrication and construction supervision for inexperienced types of long-span bridges.

2.2.2 Current International Project in Cooperation with Japanese Consultant Firms

One of the latest the Project being executed in China in cooperation with Japanese consultant firm is to be introduced in this subsection.

This long span steel truss suspension bridge, shown in Figure 2, is constructed on the mountainous area in Guizhou province in south of China, the span length of which is 1088m; it will be the seventeenth longest span of existing the suspension bridges in the world toward the completion in 2011. The design stage including detail design, construction drawing and demolition analysis has been performed by CCCC Highway Consultants in China under supervision of the ministry of communication. A Japanese consultant firm has implemented the independent check to provided technical advices on the design stages.

Figure 2: General Drawing of Guizhou Balinghe Bridge, Prepared by CCCC Highway Consultants Co.,LTD.
2.2.3 Independent Check on the Design Stage

The independent check, the verified items of which are enumerated as follows, utilizing the Japanese design codes, was performed in order to confirm appropriate validity and structural safety for the design stage performed by Chinese consultant firms. In this subsection, several verification results such as the trussed chords and the suspender cables as a part of the cable system are to be introduced.

i) Confirmation of deformation and safety under static loads such as dead, live, wind loads and thermal effects.

ii) Safety check during construction stage.

iii) Aerodynamic stability based upon eigenvalue analysis

Various design codes utilized by both the stages such as the design stage and the independent check stage are enumerated as follows. In the independent check stage, design loads were applied based upon the Chinese design code and the results of the design stage.

2.2.4 Application of Design Codes Utilized for the Detail Design.

i) Technical Standard of Highway Engineering (JTG B01-2003, China)

ii) Wind-Resistant Design Specification for Highway Bridge (JTG/TD60-01 2004, China)

iii) General Code of Design of Highway Bridge and Calvert (JTG D60-2004, China)

iv) Structural Steel for Bridge (GB/T 714-2000, China)

v) Carbon Structural Steels (GB700-88, China)

vi) Quality Inspection and Evaluation Standards for Highway Engineering (JTJ071-98, China)

2.2.5 Application of Design Codes Utilized for the Independent Check

i) Specifications for Highway Bridges Part I, II (Japan Road Association, 2002)

ii) Design Standards of Superstructures for Long-Span Bridges (Honshu-Shikoku Bridge Authority)

iii) Wind-Resistant Design Specification for Honshu-Shikoku bridge (Honshu-Shikoku Bridge Expressway Co., LTD, 2001)

iv) Technical Standard of Highway Engineering (JTG B01-2003, China)

v) Wind-Resistant Design Specification for Highway Bridge (JTG/TD60-01 2004, China)

vi) Standards of Fatigue Design for Steel Highway Bridge (Japan Road Association, 2002)

vii) The Japanese Industrial Standards ("JIS") utilized for steel and relevant materials

2.2.6 Design Loads

Design loads applied to the independent check were basically utilized based upon the drawings prepared by Chinese consultant firms. The live loads, design wind velocity and gust factors were applied based upon the Chinese design codes mentioned above. The load combinations were determined based upon JDSS, enumerated as follows.

i) Dead loads + Live loads + Thermal effects: D+L+T

ii) Dead loads + Thermal effects + Wind loads: D+T+W

The required additional factor of 1.5 was considered under the wind loads combination.

2.2.7 Safety Evaluation of Upper And Lower Chords

The following figures show distribution of axial forces occurring in the upper and lower chords. The green lines indicates the axial forces caused under the live loads such as D+L+T; the blue lines indicates the axial forces considering the required additional factor under the wind loads such as D+T+L/1.5; the red lines indicates allowable axial forces calculated based upon JSHB. For the steel specifications, the steel SM490 specified in JIS was applied to the independent check stage because the SM490 is metallurgically equivalent to the steel Q345 that is a Chinese steel specification applied to the design stage.

As shown in the figures, the axial forces occurring in the chords meet the allowable axial forces within valid differences although the results are obtained under the live loads specified in the Chinese design code.

2.2.8 Safety Evaluation of Suspenders

The rupture tensile force and the material specification of the suspenders were determined in the design such as Tb=6600 KN/suspeneder (8x41SW+1WR D=52mm-4 strand wire ropes). The maximum tensile force of a suspender occurred in a case under the load combination including live loads. Figure 4 and Table 2 show the
location of the extracted suspenders and the tensile forces. The tensile forces occurring in the extracted suspenders meet the allowable values considering the safety factor of 4.0. In comparison with the load combination utilizing the Japanese live loads specified in JSHB, generated tensile forces meet the results using Chinese live loads within four present.

![Figure 3: Distribution of Axial Forces in Upper and Lower chords](image)

![Figure 4: Location of Extracted Suspenders](image)

<table>
<thead>
<tr>
<th>Suspender No.</th>
<th>Unit</th>
<th>1313</th>
<th>1327</th>
<th>1339</th>
<th>1351</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile Force</td>
<td>KN</td>
<td>1591</td>
<td>1602</td>
<td>1623</td>
<td>1632</td>
</tr>
<tr>
<td>Rapture Strength</td>
<td>KN</td>
<td>6600</td>
<td>6600</td>
<td>6600</td>
<td>6600</td>
</tr>
<tr>
<td>Allowable factor</td>
<td></td>
<td>4.1&gt;4.0 OK</td>
<td>4.1&gt;4.0 OK</td>
<td>4.1&gt;4.0 OK</td>
<td>4.0&gt;4.0 OK</td>
</tr>
</tbody>
</table>

The design concepts specified in the Japanese design codes are widely incorporated into the Chinese design codes although the traffic loads are slightly different from those specified in JSHB. We will continuously observe the technical development relevant to the design codes compiled in China comprehensively in the future, and will investigate further developed considerations relevant to the differences between the Chinese design codes and foreign ones from engineered aspects.

2.3 Application of Design Codes in the Socialist Republic of Vietnam

2.3.1 Recent Technical Cooperation of Japanese Consultant Firms

Vietnam is remarkably being developed under various financial and technical investments aided from advanced countries; however, the improvement of the technical field relevant to steel and composite structures is still stagnant behind mentioned foregoing the countries. The design concepts of the Vietnamese design codes basically are based upon limit state design method utilizing load factor design method, most of the chapters of which depends upon AASHTO LRFD, and are written in both English and Vietnamese. The only design loads are specified originally in the Vietnamese design codes. Recent the Projects in technical cooperation with Japanese consultant firms are being executed based upon the special Japanese yen loan granted in the Official Development Assistance (“ODA”).

![Table 2: Tensile Forces in the Extracted Suspenders](image)
2.3.2 Binh Bridge

Binh Bridge shown in Figure 5 is located in Haiphon city in Vietnam. This project was the first project financed by the special yen loan granted in December 1998. The bridge consists of 17-span continuous steel and pre-cast RC slab composite girders, the three centre spans of which are cable-stayed types. In the design stage, the specifications of the bridge were determined by applying the Finnish design codes in accordance with Vietnamese road specifications; however, the Japanese special yen loan was realized after the design stage; several material and structural specifications have been modified based upon the Japanese design codes.

![Figure 5: Binh Bridge: Steel Cable-Stayed Bridge (260m)](image)

2.3.3 Can Tho Bridge

Can Tho Bridge shown in Figure 6 is being constructed in Can Tho city. The main span will be 550m, which will be the longest cable-stayed bridge in Vietnam after the bridge completion. The deck and girder were designed as a hybrid structure. For the main span of 550m, the centre area, the length of which is 210m, will be composed from steel deck box girders; the other area will be constructed by PC box girders, the shape of which was designed as similar shape to steel deck of the centre area. The reasons are described as follows.

i) Generally, both of bending moments and axial compressive forces occur in the deck of a cable-stayed bridge. The deck is under full compressive condition except the centre area where bending moments are predominant over other sectional forces. Therefore, the steel structures, which will attain remarkable reduction of dead loads in comparison with PC structures, were applied to the centre area where tensile stress was predominant due to the bending moments.

ii) If PC box girders were applied to the centre area continuously, injurious stationary uplifting forces would be caused in the side spans; thus, the steel structures were applied to the centre area in order to reduce the stationary uplifting force without any counterweights.

Although such the projects executed by Japanese financial aid have been generally performed by applying the Japanese design codes, this bridge project is basically based upon AASHTO LRFD and partially the original excitations specified in the Vietnamese design codes. Consequently, the specifications of steel and other materials specified in JIS were partially and carefully applied to the bridge in order to maintain the design concepts specified in AASHTO LRFD because the monolithic combination of load strength, load factors and design methodologies would form an essential design system.

![Figure 6: Can Tho Bridge (Rendering Drawing)](image)
2.4 Application of Design Codes in Oceania

Recent the Projects in Oceania in technical cooperation with Japanese consultant firms have been executed based upon the special Japanese yen loan granted in ODA. Because the aided countries are almost island countries on the Pacific Ocean, steel or composite bridges, which would be weak against corrosions, have been avoided to be constructed by Japanese consulting firms and relevant organizations.

Therefore, an example of the Independent State of Papua New Guinea ("PNG") where a lot of steel bridges aided by Australia and Japan is to be introduced in this subsection. The example is the urgent rehabilitation project of Markham Bridge shown in Figure 7. The bridge is the longest steel girder one in PNG, the superstructure of which consists of 3x5-span continuous steel girders erected by the financial aid of Australia in 1973. The major purposes of the project relevant to steel and composite structures were evaluation of proof strength of the superstructure under increased traffic loads.

![Figure 7: Current Markham Bridge](image)

The PNG’s design codes relevant to steel and composite structures are not compiled by themselves; they have just only the seismic design standards and the flood estimation manual, both of which were compiled in technical cooperation with New Zealander and Australian firms respectively. The major design codes, utilised for this rehabilitation project, are enumerated as follows.

i) Specifications for Highway Bridges Part I, II (Japan Road Association, 2002)
ii) Australian Standard “Bridge design Part2: Design loads • AS 5100.1-2004
iii) Standards of Fatigue Design for Steel Highway Bridge (Japan Road Association, 2002)
iv) JIS (Japanese Industrial Standards) utilized for steel and relevant materials.

3 CONCLUSION

In this report, several bridge types and application of the design codes relevant to steel or composite structures utilized in international long-span bridge construction projects executed in Asian region in cooperation with Japanese consultant firms are introduced. Additionally, noteworthy considerations for the applicability are also described.

In immediate future, the design concepts of steel or composite structures specified in the Japanese design codes will be revised in order to apply load factor design method; consequently, the actual results of the Project applying new revised the Japanese design codes will be increased although AASHTO LRFD or Euro Code based upon such the design methodology have been applied until now to several the Projects even executed by Japanese financial aids.

However, most of the developing countries have still few accumulations of related studies and engineered technical experiences; the design codes or technical specifications have not been improved or compiled comprehensively. Accordingly, multiple the design codes compiled in different countries are being collectively applied to the Projects; hence, various technical irrationalities between engineered considerations and fundamental design concepts would occur in several significant the Project. Therefore, the bridge engineers cannot but rationally apply multiple the design codes evaluating each the design concept and methodology based upon their accurate engineered considerations.

Consequently, the development of the unified design code such as the Asia Code, which should be compiled to be incorporated with various studies and engineered technical experiences accumulated in various the major design codes, is extremely informative for the bridge engineers being involved with such the Projects.
REFERENCES