The Scheme and Its Management of Autonomous Public Authority in Realizing Innovations onto Expressway Bridges

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Abstract

The scheme of executing a mega project of concrete bridge construction for expressway in Japan is reviewed. The autonomous public authority, JH, Japan Highway Public Corporation provided that scheme in which engineers of concerned sectors, i.e., autonomous public authority, industry and university, resonated in productive and progressive mode.

The scientific principles put to practice innovatively are; the external prestressing, the replacement of girder webs by the corrugated steel webs, and above all, hybrid of extradosed prestressing and corrugated steel webs (e.g., Himi Yume bridge, JH, in Nagasaki). The construction methods have been invented in which construction procedure shifted from segmental to "fragmental" construction in which the size of structural elements were made smaller so that construction procedures adapt to diversified environment and resources, i.e., natural, industrial and human resources of the area where construction takes place.

"Death valley" which is said to exist between technology innovation and its realization onto products has been bridged over by the scheme fit to verify the quality. The internal dissemination of information and transparency by inviting external criticisms for evaluation of the new ideas exceeding the state of the arts are two functions that supported engineering ethics of the in-house engineers.

The innovative ideas and the manners of their applications to practices are eventually transferred to and assisted the bridge projects of autonomous local governments which are constantly in short in fund and man power of in-house engineers in recent advocate of "small government" (e.g., Seiun-Bridge, Tokushima prefecture).

Concrete bridges built in the last decade became shared heritage, physically, scientifically and methodically. Intelligent resources still exist but not the scheme since 2005 after dissolution of JH as autonomous entity. Whether or not the human resources be orchestrated in future again awaits ingenuity of next generation and experts of concerned trades.

Key word: autonomous public authority, innovation, expressway, extradosed bridge, corrugated steel web, construction methods

1. Power of innovation: A case of concrete bridges for expressway :

People must gain power by a good innovative bridge for expressway. The power is felt, not only because of mobility they acquire, but also because beneath the visual beauty lie scientific command, good intention for public service and harmonious orchestration of experts and academia concerned. This whole must be an example of good management. This argument is the main theme of this paper and was repeated based on various bridges in the following sections. Fig. 1 is an extradosed bridge with corrugated steel webs.

Fig.1 A Typical Innovative Bridge, Himi-Yume Bridge (Nagasaki Prefecture), JH and Mitsui-Sumitomo, Photo by courtesy of Mashiko

2. Beneficial results of good management scrutinized by its purpose, nature, and execution:

2.1 Beneficial results

A retrospect on innovative efforts by bridge engineers of the last decade must shed light for engineers of tomorrow. A breakthrough by innovative concept of the external prestressing led to the remarkable efficiency of the extradosed bridge. Whereas, sympathy to human toil invented numerous advanced methods of construction.

2.2 Purpose and nature of good management as executed by Freyssinet

Freyssinet's statement of the "art of building" quoted by Billington [1] "as a means of reducing to the extreme, the human toil necessary to attain a useful goal" sounds valid in the current adverse wake of globalization in economy. May his spirit be emulated when constructing infrastructure additions to existing community by respecting nature, culture and sustainability of wholesome life.

2.3 Management of construction of expressway is in mega scale

Expressway bridge construction in Japan was once a "mega" project. The "mega" scale ingenuity grew in the autonomous public authority responsible for expressway construction, i.e., Japan Highway Public Corporation, abbreviation JH, may have been the source of progress in scientific expertise and intelligent scheme adequate for innovative construction, when the geographically vast extent of expressway involved numerous number of bridges and engineers, and above all, peoples' life and future of the nation.

3. Why JH had to end ?

The in-house engineers of the JH fulfilled responsibility of plan, design, verification, research, quality control and assessment, and had kept advancing expertise for bridge construction. End of an era came in 2005. The JH was transformed and divided into three regional private companies and one research institute to which engineers from three companies are stationed on temporally basis. An expressway holding agency was newly created with close relation with the ministry of land, infrastructure and transportation. Although they are not within scope of this paper, similar transformation was executed on Tokyo and Hanshin Metropolitan Expressway Public Corporations and Honshu-Shikoku Bridge Crossing Authority. In probing heal of injure from the transformation and as a reference for creating a scheme for revival of the project, a review of the JH is given in the next section.

4. Review of expressway project of Japan: Background and scheme of JH and NEXCO

4.1 Beginning and support by advisors

"The roads of Japan are incredibly bad. No other industrial nation has so completely neglected its highway system" was the leading statement of the "Report on Kobe-Nagoya Expressway Survey, 1956" by a six men team, experts in economics and one engineer, chaired by Ralph J. Watkins. This report was to be assessed by World Bank who was reluctant to Japanese solicitation of the loan. The team traveled along the route, met numerous people of varying trades. Recommendation advised affirmatively and enthusiastically quick start of construction of expressway. The report was reviewed immediately by a Japanese team chaired by the inaugurating president, Dozo Kishi, of the new autonomous public authority, Japan Highway Public Corporation, JH, which had been founded a few months before. The review team has been impressed by the thoroughness of facts compiled from field survey. Diligent reasoning persuaded negligence and reluctance.

4.2 Effect of highway on this nation

The effects of highway on nation's economic growth and even far reaching implication for resurrection from wartime devastation and enrichment of life of the people proved itself in following years.

4.3 Funding scheme

Funding schemes to cover the cost of construction were defined, i.e., toll collection, and loan from people's savings handled by then public post agency. New taxation created was that tax on gasoline was to be exclusively spent for roads. But, this fund was mostly spent on ordinary national and prefectural roads, and portion of expenditure on expressway has been small. Thus the project was given momentum by people from varying sectors who could create schemes. However, in recent years, those two schemes have been much in dispute, and preference of expressway budget was drastically reduced.

5. How JH managed construction

5.1 Major project in the last decade, 1997-2005

In the last decade, 1997-2005, expressway construction in Japan focused on completion of the second artery to join Tokyo, Nagoya, Osaka and Kobe, the nation's production megalopolis 600km in distance. This route is a lifeline both in ordinary time and even more in the event of severe earthquakes threatened by recent records in the archipelago. The first artery has long become chronically over-loaded and its structures deteriorating.

5.2 Decision process of JH

The legendary JH, 1956-2005, commanded its decision process of bridge projects. Proposals from its numerous regional construction offices were encouraged. Technical innovations without previous execution were reported first to the director of the engineering of the head office. When this assessment is passed, the proposers were welcomed to report directly to the executive director in charge of engineering.

Engineering and administrative responsibilities were tightly linked. Once decision is made, new information was conveyed through all district offices to all engineers. Dissemination system functioned. For important technical subjects which exceeded state of the art, JH often set up committees to which academia and other outside experts were invited. This was one scheme which maintained transparency and technical credibility. Enthusiasm and morale toward excellence in their missions and ethical confidence of the in-house engineers were thus maintained on the scheme of autonomous management of JH.

6. Administration reform

6.1 A process of a so-called "privatization"

Administration reform has been a usual slogan of the cabinets, and the JH was made one of the targets of re-structuring. A committee was set up to give the recommendation of what the new scheme should be. The committee consisted of seven experts from selected expertise, after intensive efforts, gave resolution, but not unanimously. Public announcement mentioned importance of debt repayment. Within the limit of publically announced resolution, its view on the functional role of freeway for the nation, neither conceptual design of the scheme to that effect, may have fell short from view point of civil engineering study.

6.2 New organization, NEXCO

The JH was dissolved into three organizations, west, central and east Nippon expressway companies and a research institute in 2005. Each company carries in its name NEXCO in common. An administrative agency was newly created, of which name means the organization for expressway holding and debt repayment. The engineers of JH were separated into either one of the three organizations. Some of the chief executive officers were invited from private manufacturing industry presumably to merge private industry and public work for good. Assertions on the cause of transformation of JH to NEXCO by the cabinet might have been better understood by public and experts, if the results of the study of the committee have been made available in an informative way, for example, such as Watkins report (1956).

7. Retrospective assessment

Numerous bridges of new concepts emerged in the projects by JH. Quality assurance of advancing concepts and technology is rooted on rigor in science and determination in execution. This practice was inherited by Kadotani who became the last director of engineering with forty nine years tradition.

Whether the excellence of technology based on the ethics of the civil builders' profession be maintained in the new scheme is yet to be seen. Hence, the projects conceived by the JH are recorded here, lest they may become history.

8. Conditions imposed on technical solutions for the current bridge construction

Detrimental conditions particular to the current project are seismic intensity, humid and hot summer, cold and snowy winter where spray of deicing sodium chloride is inevitable, illegally over loaded trucks and mountainous terrain. Cost reduction requirement increased its severity every year, which meant reduction of initial cost and extension of service life. In and near inhabited areas, demand to reduce impact to the surroundings during construction became tougher. Passages of expressways through inhabited areas occur not only within city centers but also in the suburban areas where highways must merge into local access roads. In all cases mentioned above, reduction of own weight of the bridge superstructure and cautious means to improve durability are common demands for technical solution..

9. Pioneering works of key technologies

9.1 Breakthrough a decade ago

The external prestressing, the extradosed prestressing, and hybrid between prestressed concrete and corrugated steel webs or steel truss webs, were emerging technology in France and Switzerland. Those were breakthrough also in concepts which attracted the bridge experts of Japan in preparation of construction of the second artery.

9.2 New concepts of the bridges studied a decade ago

Technical exchange was kept active between JH and SETRA, the research institute for expressway of France. The bridges to be studied were: for corrugated steel webs, Dole bridge [2] and Maupre (near Charolles) viaduct, for steel truss webs, Echinghen (near Boulogne-sur-mer) viaduct [3], Arbois and Roize[4] viaduct, for concrete truss webs, that preceded introduction of steel truss webs, Sylans and Glacieres viaduct [5], for extradosed prestressing, Sunniberg bridge of Switzerland [6],with straight multiple stay cables system, though her designer Menn does not use the term extradosed bridge, and for the another type extradosed bridge with continuous draped tendon, St Remy de Maurienne bridge.

9.3 External prestressing

Both types of hybrid bridges incorporating corrugated steel webs or steel truss webs benefit from external prestressing. Treatises by Virlogeux compiled in a book by French society of civil engineers [7], and a proceedings of work shop held by the same [8] describe in detail and extensively concept and construction of externally prestressed girder bridges. According to the report the idea of external prestressing was realized in a bridge as early as 1936 in Germany. Extradosed bridge is also introduced in this report [7].

10. External prestressing: Freedom in design but cautious detailing required of reinforcing

10.1 Freedom in design by external attachment of prestressing steels

Prestress force exerted on beams externally prestressed can be treated by the same manner as classical method by Freyssinet and Guyon developed for internally prestressed concrete beams. In external prestressing system, there is freedom of creative arrangement of tendons. However, there are certain safety requirements for concrete sections and tendons as follows.

10.2 Reinforcement detailing particular to externally prestressed beams

Internal prestressing steels restrain crack openings in concrete. Relocation of prestressing steels from inside of concrete beams to outside leaves some areas unreinforced and thus vulnerable to brittle failure. Therefore, cautious envision of flow of forces and addition of auxiliary reinforcement are of vital importance. The areas surrounding deviators (deviator: protruding portion for attaching external tendons to concrete section and in many cases where the direction of tendons are deviated) must be carefully reinforced. It calls for finding flow of forces in the periphery of deviators in service limit state and ultimate limit state.

10.3 Safety requirements for external tendons

When the tendons are deviated, the contact interfaces of strand wires are vulnerable to fretting fatigue under fluctuating stress due to live loads.

For extradosed bridges the stay cables are continued on top of the saddle, where the situation for tendons are similar to that at deviators, meaning similar care against fatigue is required.

Durability of external prestressing steel is vital. When external prestressing steel is installed inside the box girder, epoxy coated strands have been used often. Ordinary prestressing steel has also been used, but encased in the ducts injected with cement grout. The newly developed clear duct has been introduced in order to ascertain inspection of grout injection. Recent developments to protect external tendons are treated by Kadotani [9].

11. Advancing concrete bridges: Type and technical particularities for evolution

11.1 Extradosed bridge

The extradosed bridge proposed by Mathivat was depicted by a model in [10]. The photo showd a configuration like a cable-stayed bridge but with much lower pylons which support stay cables. Most of the extradosed bridges built are of this type. The lower the pylon, and hence, the smaller the eccentricity of cables, the lower the fluctuating stress due to live loads in cables, and vice versa.

Fig.2 Extradosed bridge, Kiso-gawa and Ibi-gawa bridge, 275m (JH)

Although its figure is similar to cable-stayed bridges, it may be convenient for understanding the load bearing nature of this structure concept, to consider the extradosed bridge as a girder bridge with external tendons which are located with large eccentricities. The eccentricities of the tendon can be either top or bottom side of the girder to give uplift force to the girder. It is preferred for the reasons of looks and constructability to set the eccentricity "on the top side of the girder". Thus, the terminology, "extradosed" is used (French terminology: la precontrainte extradossee).

A merit of extradosed bridge over ordinary girder bridge is the reduction in depth and cross section of the girder. It is achieved by reduction in prestressing force necessary to resist design bending moment by virtue of increased eccentricity of cables.

A merit of extradosed bridge over cable-stayed bridge is that the anchorage grips for tendons can be those used for conventional internal prestressing tendon system, when the eccentricity of tendons are limited within the range so that the fluctuation of stress in tendon system due to live load is limited within the range safe against fatigue failure. In such a case, the allowable stress in tendon is set at 0.6 times rupture stress, in contrast to 0.4 times rupture stress in case of cable-stayed bridge.

An extradosed bridge with longest span in Japan, 275m, is shown in Fig.2, [11], Kiso-gawa and Ibi-gawa bridge. The depths of the girder on supports are 7.5m.

For this unprecedented attempt numerous precautions have been taken. One is reduction of dead load by incorporating steel girder in the mid

Fig.3 Conventional girder bridge with internal tendon, Eshima bridge, 250m, (Tottori and Shimane prefecture and Kajima)

third length of the span. It contributed to a certain extent to reduction in depth of the girder.

For comparison of girder depths, an ordinary girder bridge with internal tendons with center span of 250m and girder depth 15.5m is shown in Fig.3, Eshima bridge [12]. The depth of the girder of the extradosed bridge is roughly one half of the girder bridge.

Fig.4 Extradosed bridge, Tokunoyama-Hattoku bridge, 220m, (Japan water agency and Oriental)

A more remarkable figure depicting the power of extradosed prestressing is Himi Yume bridge, which was shown in Section 1., Fig. 1.

Another figure of extradosed bridge with cables continuous between two ends of the continuous bridge is seen on St Remy de Maurienne bridge, Fig.5. This figure depicts a statics law which governs the load bearing nature of extradosed bridge, i.e., “the coordinates of the continuous tendon are calculated in the same manner as that used for ordinary pestressed concrete girder with internal tendons, for example, the classical method by Freyssinet and Guyon, but, the calculated coordinates simply lie outside of the profile of the girder”.

Fig.5 Another type of extradosed bridge, St Remy de Maurienne bridge, France

11.2 Corrugated steel webs

Another innovation also of French origin was to make a hybrid of prestressing and corrugated steel webs replacing concrete webs of box beam. A merit of this hybrid is saving in prestressing force.The corrugated steel web does not resist compression, thus prestressing force applied to the beam is transferred only to top and bottom concrete slabs where prestress is needed. This in turn enables reduction in concrete cross section and dead load. Shear capacity needed for webs is provided by corrugated steel webs with its corrugated configuration resisting out-of-plane deflection which is the mode of buckling vulnerable if steel plates were flat and subjected to diagonal principal stresses due to in-plane shear. A typical box girder bridge with corrugated steel bridge is shown in Fig.6, Akabuchi-gawa bridge.

Fig.6 A typical box girder bridge with corrugated steel bridge, Akabuchi-gawa bridge, (Central-NEXCO and Sumitomo)

11.3 Hybrid of corrugated steel webs and extradosed bridge.

Combined use of corrugated steel webs and extradosed prestressing or stay cables is also effective. Extradosed bridge with corrugated steel webs first completed is shown in Fig.7, Himi Yume bridge [13]. The bridge deck carries two traffic lanes. For the center span length 180m, the constant depth of one box girder is 4m. The height of the pylons is 19.8m, or 1:9 of the span length.

Fig.7 Extradosed bridge with corrugated steel webs, first completed, Himi-Yume bridge, 180m, (JH and Sumitomo)

The one of which construction started earlier is shown in Fig.8, Ohmi Ohtori (Ritto) bridge [14].

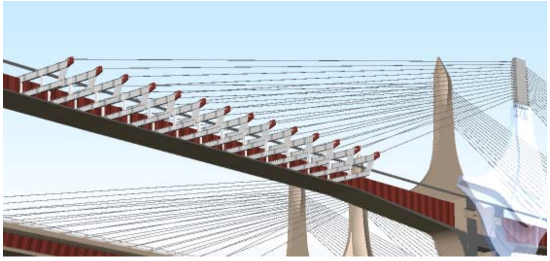

Fig.8 Extradosed bridge with corrugated steel webs, first started construction, Ohmi Ohtori (Ritto) bridge, (JH and PS and Maeda)

This was the signature bridge for the first congress of *fib* (International Federation for Structural Concrete) 2002 Osaka, by corporation of France (innovative technology), U.S.A (architectural design) and Japan (owner and builder).

11.4 Hybrid of corrugated steel webs and cable-stayed bridge

Cable-stayed bridge with corrugated steel web of very wide road width is shown in Fig.9, Yahagi-gawa bridge[15].

The unique diamond shape of pylons is artificial, which was necessary because the width of the site of the piers were strictly limited. This caused very heavy reinforcement and prestressing and confinement of conrete in the steel shell at the bend of the pylons.

11.5 Steel truss webs

Another hybrid bridges of prestressed concrete and steel truss webs were also constructed. Here, truss

Fig.9 Cable stayed bridge with corrugated steel webs, Yahagi-gawa bridge, (JH)

webs have merits similar to those of corrugated steel webs, namely, non-resistance to prestress and enough resitance to shear. Fig.10, Saruta-gawa and Tomoe-gawa bridge incorporates steel truss webs, constructed for first expressway bridge, and Fig.11,

Fig.10 Steel truss webs, Saruta-gawa and Tomoe-gawa bridge, first expressway bridge, (JH and Ohbayashi)

Kinokawa bridge [16] is a similar type built earlier for local national highway proposed by a contractor. For jointing steel tubular diagonals at truss nodes, indirect jointing, steel-to-concrete-to-steel splicing was developed when the shear is low, which relaxed alignment allowance during construction considerably.

Fig.11 Steel truss webs, Kinokawa bridge, first highway bridge, (MLIT and Kajima)

11.6 Strutted and ribbed top slabs and versatile evolution of construction methods.

Use of struts to support overhanging top slabs and reducing size of center core box caught up with practice of other countries, i.e., Kochertal viaduct in Germany [17] and Rogerville viaduct in France [18]. This technique contributed to reduction in weight of the beam. The ribs attached under the top slabs give similar effect. The reduction in dimension of the core box section simplified connection with piers. This has merits in particular for continuous girder bridge with high piers. Fig.12, Shibakawa viaduct [19] with very high piers incorporates strut supported top slabs.

Fig.12 Strut supported slab of the bridge with very high piers, Shibakawa viaduct, (JH and Oriental)

This configuration of strutted top slab structure calls for several construction stages, i.e., that for core box, struts and top slabs. As compared to monolithic concrete box girder, this can add more elaborate construction procedures which demand increase in time and labor. Meritorious aspect is that it opens to versatility of construction procedures. Some of the structural elements can be precast and construction machinery can be small sized, since the structural elements to be handled during construction is reduced in scale compared to the case where entire cross section is monolithically cast. This is meritorious when construction environment is constraining, like urban areas where conflict with human activity is severe, or, rural areas or rough terrain. Application in various forms is shown in Section 12.4, “fragmental construction”.

11.7 Compressive strength of concrete

For most of the bridges reported here the compressive strength was up to ordinary class around 40MPa. A 60Mpa class concrete was used in special cases, i.e., Kiso-gawa and Ibi-gawa bridges where large precast segments weighing up to 400 tons were used. However, merits of higher compressive strength are recognized. A specific application of high strength concrete and high strength reinforcing steel was for high piers. The purpose was to extend the natural period of long span rigid frame bridge for seismic safety, by reducing the dimension of cross section, Fig.13, Washimi bridge [20].

High strength capacity of concrete is not yet fully exploited for bridges compared to tall buildings where strengths around and above 100MPa are used.

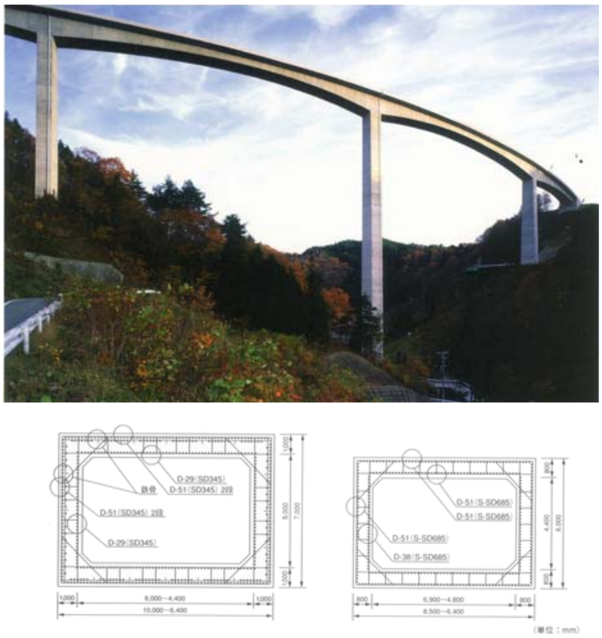

Fig.13 High strength materials to extend natural period, Washimi bridge, (JH and Kajima)

12. Further evolution: Breakthrough in structural concepts and materials followed by versatile methods

12.1 Evolution by interaction between autonomous public authority, university and industry.

Once a new concept of structure is established, versatile structural forms and construction methods flourish. The autonomous public authority and universities took part in the role of establishing new concept of structures. Industry also developed new concepts, in particular, from view point of construction and sometimes from view point of dismantlement.

12.2 Dual functions of cables: Construction platform and self-anchored tendon

To construct a single span bridge in a site condition with poor soil at abutments and non accessible terrain under, a composite truss was developed which uses suspension tendons ground anchored temporarily during construction which is eventually anchored to the bridge to serve as prestressing tendons. Started as a laboratory study by Ikeda (professor emeritus, Yokohama national university),Fig.14, [21],

Fig.14 Suspension cable supporting roads, externally anchored during construction, and afterwards self-anchored, (Yokohama National University)

it found its realization at a span length up to 97m, Fig.15, Seiun bridge, [22].

Fig.15 Suspension cable supporting roads above, construction bottom up, Seiun Bridge, (Tokushima prefecture and Sumitomo)

The statics law governing the load bearing mechanism has affinity to the extradosed bridge, since, the structure can be considered to be a girder (road deck) with external tendons (bottom chord suspended slab) of large eccentricities. Now using the same structure concept but with modified construction procedure to increase stability and ease of construction with two systems of suspension cables, a foot bridge was constructed “from top downward”, Fig.16, Seishun bridge [23].

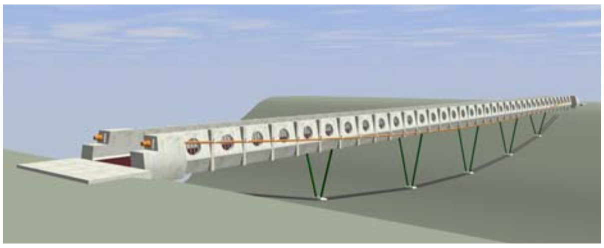

Fig.16 Suspension cable supporting roads above, construction top down, Seishun Bridge, (Gumma prefecture and Sumitomo)

12.3 Ultra high strength fiber reinforced reactive compound

Ultra high performance fiber reinforced compound (UFC) invented in France was used only in limited cases yet. The UFC has been utilized for a few foot bridges and road bridges, but its impact on revolutionary potential to change the shape of the bridges is recognized, Fig.17, Haneda airport ground support equipment runway bridge [24] and

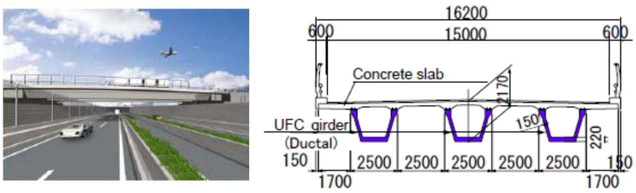

Fig.17 Slender and straight profile of beam by UHPC, Haneda airport ground service equipment bridge, Rendering, (MLIT and Taisei)

Fig.18, Mikane-ike bridge [25]. Genuine beauty of straight line of the beam is seen with depth to span length 1:40 for a foot bridge.

Fig.18 Slender and straight profile of beam by UHPC, Mikane-ike foot bridge, (Ohnojou city, Fukuoka prefecture and Taisei)

12.4 “Fragmental” construction: Strutted and ribbed top slab of box girders.

Fig.19 “Fragmental” construction in city center, Shin-Meisei bridge, (Nagoya city expressway nd Sumitomo)

As in the case of strutted or ribbed top slab, Section 11.6, certain structural forms necessitates construction in “fragmented” stages, unlike “segmental” construction where the segment means a transversely cut portion of girders. One merit of “fragmental” construction noted in Section 11.6 is encouragement of industry to create imaginative construction methods. Its applications are those for the middle of the congested city, Fig.19, Shin-Meisei bridge [26],

or for suburban areas where transport of heavy construction machinery is unpractical for residential environment or farms and orchards, Fig. 20, Uchimaki viaduct,

Fig.20 Strutted top slab, in suburban areas, Uchimaki viaduct, (JH and Kajima)

and Fig.21, Yamagiri viaduct.,

Fig.21 Strutted top slab, in suburban farming areas, Yamagiri viaduct, (JH and Sumitomo)

Fig.22, Katsurashima viaduct [27] is the construction by incremental launching, where reduced dead load is advantageous .

Fig.22 Strutted top slab and corrugated steel webs, incremental launching, Katsurajima bridge, (JH and Sumitomo)

12.5 Utilization of corrugated steel webs during cantilever construction.

For cantilever method, corrugated webs can serve as support of bottom and top slabs during construction, Fig.23, Akabuchi-gawa bridge.

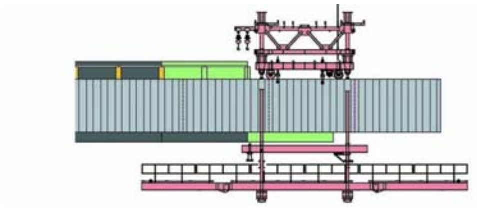

Fig.23 Corrugated steel webs, free cantilever construction, Akabuchi-gawa bridge, (Central-NEXCO and Sumitomo)

12.6 Utilization of corrugated steel webs during incremental launching construction with ultra-high strength compound.

An elaborate application was made for incremental launching. The UFC was used for the bottom flange of box beam with corrugated steel webs. Reduced weight of the beam made it possible to use the beam of the end span as the erection nose, Fig.24, Torisaki-gawa bridge [28]. The reduction in dead load and high strength were the keys for this construction concept. Then, the temporary erection nose, customary made of steel and scrapped after completion, can be eliminated, which adds to savings.

Fig.24 End span using UHPC serving as erection nose during launching, Torisaki-gawa bridge, (JH and Taisei)

12.7 Seismic design and durability

Seismic design and durability are mandatory in Japan, but they cannot be treated in this paper due to limitations of the writer. Only general remarks are given. The "Standard Specification" by Japan Society of Civil Engineers is a basic document and the specification by Road Association gives the practical guides. Verification of seismic safety must be based on response analyses for ground motions of specified seismic waves. Inelastic behaviors are assumed. The bridges with shorter natural periods, e.g., viaducts with short piers, employ partial base-isolation by bearing shoes incorporating rubber with damping capacity.

Durability is considered utmost importance at interface between steel and concrete. To that effect, study of flow of forces that mitigate separation of interface, shaping the vulnerable parts fit for water run-off and sealing by water repelling materials have been studied. Their effectiveness is being monitored. Durability of external tendons has been mentioned in Section 10.3.

13. Concluding remark

Concrete bridges built in the last decade became shared heritage, physically, scientifically and methodically. The innovative applications of scientific principle are the external prestressing, the extradosed prestressing, replacing concrete girder webs by the corrugated steel webs, and hybrid of extradosed bridge and corrugated steel webs. The examples of construction methods are, segmental and fragmental construction in which the size of structural elements were made smaller so that construction procedures adapt to diversified environment and resources, i.e., natural, industrial and human resources of the area where construction takes place. Also mentioned was the scheme of executing a mega project of concrete bridge construction for expressway in Japan. The autonomous public authority, JH, provided that scheme in which engineers of concerned sectors, i.e., autonomous public authority, industry and university, resonated in productive and progressive mode. Intelligent resources still exist but not the scheme since 2005. Whether the human resources be orchestrated in future again awaits ingenuity of next generation.

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