The importance of bridge planning in bridge design

Case study on the Hiroshima South Road Ota-gawa River Flood Channel Bridge

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Abstract: This essay describes features of the winning proposal of the "Hiroshima South Road Ota-gawa River Flood Channel Bridge Design Proposal Competition," which was the second international bridge design competition carried out in Japan. The bridge is located near the Seto Inland Sea and consists of a cross-river part and west viaduct. A major condition of the bridge was that a bicycle-pedestrian pathway was to be placed side-by-side with an expressway. Fifteen proposals were widely submitted by a wide range of design firms including a number from Spain and France. Ours was chosen as the implementation plan. We believe that a bridge should be instrumental in creating new places and a landscape aiming to contribute to local planning. So our design concepts were "a bridge which gives the local people a strong impression of a hometown landscape" and "a bicycle-pedestrian pathway that would be enjoyable to cross as well as being user-friendly". In order to materialize these concepts, our bridge planning was carried out with comprehensive consideration of design, function, and structure. this essay aims, through our design deliberation process for the competition, to indicate the importance of bridge planning in bridge design.

Keywords: international bridge design competition, bridge planning, aesthetic bridge design

1. Introduction

Hiroshima City held an international competition, the 'Hiroshima South Road Ota-gawa River Flood Control Channel Bridge Design Proposal Competition' in 2009. This was the second international bridge design competition in Japan, following the 'Heiwa-Ohashi Pedestrian Bridge Design Competition' in 2008 by the same city, and is noted as an advanced example of a local authority aiming to improve good urban city planning. We participated in this competition as designers and our proposal was chosen as the winning entry. In this essay we will report on a summary of the design competition as well as aim to point out how a bridge can contribute to local planning by describing in detail the deliberation process of our proposal making.

Although there are several existing studies on the process and results of bridge design, the number cannot be described as great. As a typical example, Nagami et al. refers to the design competition for Namchang Bridge in South Korea and describes in detail, through the deliberation process, the relationship of design concept and formative design [1]. Sasaki et al, targets a pedestrian bridge converted from an historical truss bridge, describing the design process as well as suggesting points that should be regarded as important when re-designing bridges

[2]. These studies carefully explain with new perspectives the deliberation process from the design concept to a detailed design of the bridge, and are very valuable for actual bridge designing. This study has learnt from previous ones and is similar in that it follows the same logical steps; however a distinguishing feature is our emphasis on the bridge planning that lies between the design concept and the physical design of the bridge.

Bridge planning is the step where the design concept is shaped into a specific form taking account of natural conditions like the topography and geography of the construction site and road planning conditions like the intersecting of linear formations of roads and rivers from the structural, construction feasibility and economical points of view. In short, at this point, the outlines of linear shape, bridge length, selection of span length and structural style are decided and so it is a very important step in bridge design. Especially, as aimed for with this bridge, studying bridge design in terms of creating a place integrated with the surroundings based on the relationship of users' views and the surrounding landscape, there are many criteria that cannot be dealt with by the bridge's formative design alone, and so the planning is considered as having decisive meaning.

However, having said that, as each bridge is affected by varying given conditions, discussions about bridge planning from the design point of view have been scarce. Therefore in many cases, bridge planning was more likely aimed at seeking the optimal solution to given conditions, especially optimal solutions that could be indicated by objective figures, economics in particular, and tended to pile them up individually rather than consider the overall complicated conditions including design concept and capture it into a specific form. The only way to improve this situation seems to be to build up as many precedents of bridge planning that include design viewpoints as possible and to share them. For the reasons above, this essay aims, through our design deliberation process for the competition, to indicate the importance of bridge planning in bridge design.

2. Summary of the design competition

2.1 Summary of the design competition

The proposal competition bridge is situated across the Ota-gawa River Flood Control Channel on the Hiroshima South Road located in the coastal area of the city (Figure 1). This road is a major arterial road consisting of an expressway and a general traffic road. As this bridge is located at the point of contact of the sea and the land, and to herald the realization of 'Aquapolis Hiroshima,' the City of Hiroshima held an international competition to

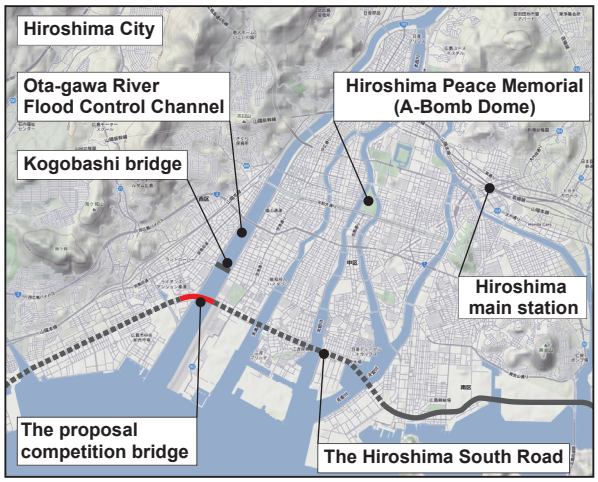

Figure 1 The proposal competition bridge location

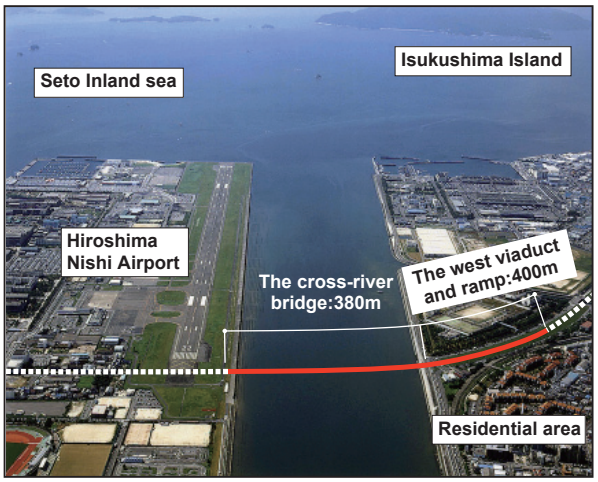

Figure 2 The proposal subject

invite superior designs that would be appreciated by generations to come.

The proposal subject is a bridge section about 0.8km in length extending from the left bank of the Ota-gawa River Flood Control Channel to the ramp at the right bank (Figure.2).

Some characteristics of the application conditions are: 1) In addition to the system where a wide range of specialist designers from the fields of architecture, urban planning and landscape can formally participate, the point to specify the person in charge of design was included. Further, with regards to all the six teams that advanced to the second and final stages had collaborating specialist designers, which proved to be sufficiently effective. 2) Not only the design work for the proposal details but also the design management was to be commissioned to those applicants with the chosen proposal. Incidentally, Schedule of the competition is as follows:

- Application period: 16th of January 2009- 22nd of May 2009
- Public viewing: 3rd of June 2009 to 8th of June 2009 (Exhibited panels at Hiroshima City Hall)
- First selection: 10th of June 2009
- Second selection: 14th of July 2009

2.2 Selection method and result

The selection of this competition was conducted by the selection committee for the Hiroshima South Road Ota-gawa River Flood Control Channel Bridge Design Proposal Competition (Table 1). The selection was conducted in two stages - the submitted documents were examined in the first stage, and public presentations (including question and interview session) were held in the second stage. The selection committee work is carried out behind closed doors, and the Selection Results Report[3)] was published after the selection.

According to this report, 21 applicants including 3 from overseas registered and 15 consisting of 13 domestic and 2 foreign nationalities (France and Spain) applied. The 6 proposals that passed the first selection went on to a public presentation, and in the Second Selection Meeting, the winning proposal, one proposal with merit, and four accepted proposals were selected. Our proposal 'Itsuku-Dashi - the bridge that fixes the sanctuary island of Aki in people's hearts - (Entrant's name: Eight-Japan Engineering Consulting Inc.) was selected as the winning proposal. The structural styles of the six selected proposals included one girder bridge, three arch bridges, one truss bridge, and one cable-stayed bridge. Incidentally, as advised by Professor Shinohara, the chairman of the selection committee, the names of not only the entrants but also the designers and collaborators were stated clearly.

Table 1: Member of the Selection Committee

Name	Special field	Affiliation
Osamu Shinohara (Chairman)	Aesthetic design of civil engineering	Professor Emeritus, The University of Tokyo
Hiroshi Naito	Architecture	Professor, The University of Tokyo
Kazuhiro Nishikawa	Structural design	Head of Research, National Institute for Land and Infrastructure Management, Ministry of Land, Infrastructure, Transport and Tourism
Keiko Hirata	Environment design	Assistant Professor, Faculty of Engineering, Hiroshima Institute of Technology
Akira Fujii	Cultural Studies	Professor Emeritus, Hiroshima Jogakuin University
Masanori Fukuda	Citizen representative	Vice Chairman, The Hiroshima Chamber of Commerce and Industry
Mutsuko Ujihara	Citizen representative	President, Gangi-gumi, incorporated NPO
Naoaki Nakamaru	Citizen representative	Vice Chairman, Association of Hiroshima Corporate Executives

Note) Dated 14th of July 2009.

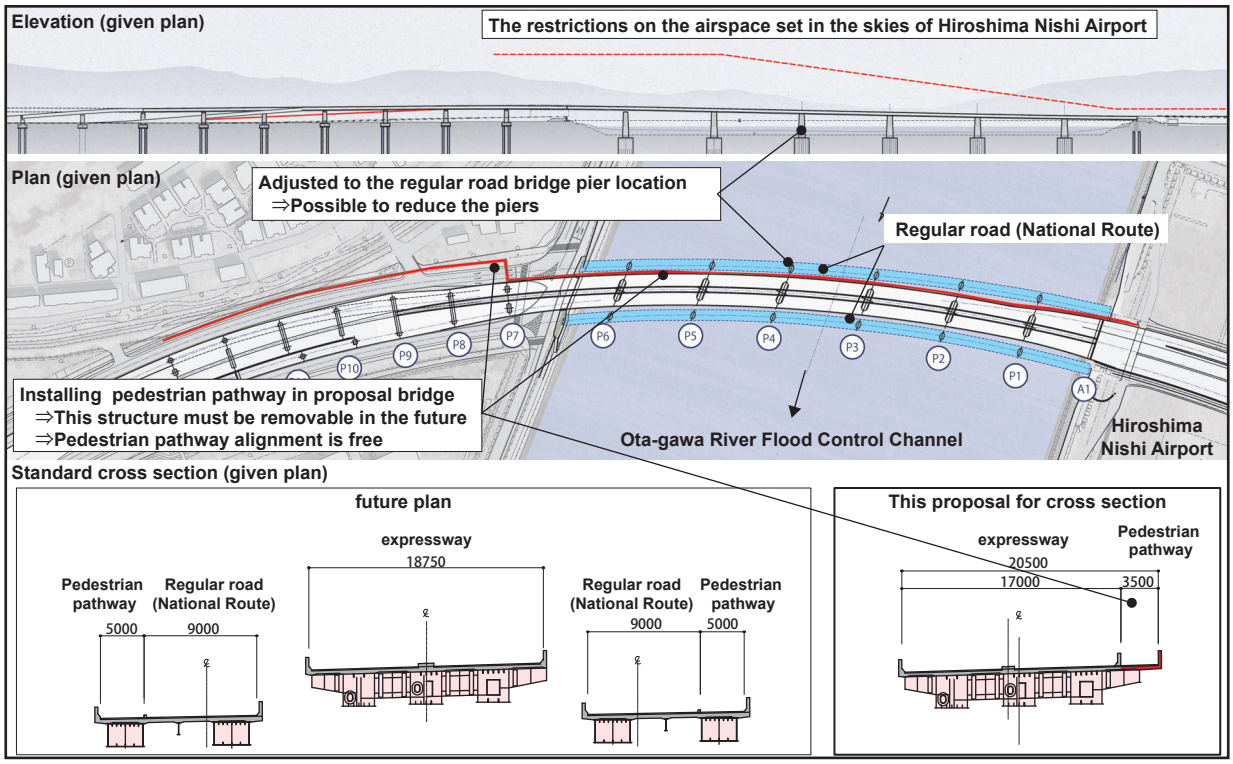

Figure 3 Main design conditions that would affect the proposal

2.3 Main design conditions that would affect the proposal

Although the structural style for the bridge was free, the following were major design conditions that might affect design proposals (Figure 3).

- As there is a plan to construct National Route bridges up- and down-stream from the Ota-gawa River Flood Control Channel Bridge, the position of bridge piers have to be adjusted to the existing National Route plan. The number of the piers can be reduced if the blocking rate of the cross-sectional area of the river is satisfied.
- It is necessary to satisfy the restrictions on the airspace set in the skies of Hiroshima Nishi Airport.
- The bicycle-pedestrian pathway must link the left embankment road of the Ota-gawa River Flood Control Channel to the roads on the right bank. The route can be designed freely as long as it fulfills the linking function and structural standards for the bicycle-pedestrian pathway; however, for when the National Route bridge is built adjacent to it in the future, the structure should allow for its removal.

3. Our team formation and roles.

Our team consists of four parties: Eight-Japan Engineering Consultants Inc., for bridge design, EAU Ltd. for spatial design, Kuukan Kougaku Kenkyujyo, architectural structure specialists, and Akiyoshi Nii at Kokushikan University, who specializes in landscape design.

The start of the team formation was when Nii, one of the authors, was invited to the 2008 Heiwa-Ohashi Pedestrian Bridge Design Competition by Ms. Yoko Kabaki of Eight-Japan Engineering Consultants Inc, who also happened to be his former boss from when he worked for construction consultants. Then he spoke to Mr. Kenichi Nishiyama from EAU Ltd., a trusted friend, and they entered the Heiwa-Ohashi Pedestrian Bridge Design Competition. That result was unsuccessful; however, as we could develop positive discussion towards the

proposal details, a decision was made for the same members to team up for this design competition too. Due to the conditions advised in this design project, there was the possibility that separating the structure of the expressway and the structure of the bicycle-pedestrian footbridge would create a superior plan; in that case, quite a unique structure could be expected. Given that situation, we had Mr. Satoshi Okamura of Kuukan Kougaku Kenkyujyo, who can deal with such structures, join us and made the team of four described above.

The main team members and their roles are as indicated in Table 2. The roles shown here are ultimately only for finishing the final proposal, and in the consideration stages, centered on the core members, the ideal bridge's proposal was discussed and refined, regardless of each person's specialty.

Table 2: The proposal team's main members and roles

Role	Name
Overall supervision	Yoko Kabaki (Eight-Japan Engineering Consultants Inc)
Advice throughout	Mitsuo Hara (Eight-Japan Engineering Consultants Inc)
Concept and bridge design	Akiyoshi Nii (Kokushikan University)
Bridge and landscape design	Kenichi Nishiyama, Sota Aniya (EAU Ltd.)
Structural design of main bridge	Yasuto Watanabe (Eight-Japan Engineering Consultants Inc)
Structural design of pedestrian pathway	Hitoshi Okamura (Kuukan Kogaku Kenkyuujyo)
Create model	Kensuke Yamakawa (Kokushikan University)

4. Design Concept

As this bridge, basically, is an expressway and needed to be elevated in the city area, what we considered important, apart from the convenience of motor traffic, was to have it make a contribution to the local area if at all possible. In order to achieve that, it was necessary not only to aim to design a bridge refined in appearance, but also a bridge that would be welcomed by the local people.

The bridge construction area has become developed along with the improvements in the flood control channel, and future development is also expected, but at present, the place does not have much historical context. On the other hand, it has its charm when looking at the seaward side where the landscape of the Seto Inland Sea stretches out with its many islands floating on the horizon. Taking these characteristics of the bridge construction site into account, the overall goal to create a new landscape where this sea and land meet, a landscape that would remain in people's memories and suit the image of 'Aquapolis Hiroshima' was raised. In order to achieve that, the bridge has to enhance the hometown's landscape. For that landscape, what we took notice of was Itsukushima Island, which has a magnificent presence seen from the bridge construction site and which has been an object of devout worship by local people since ancient times.

As described above, the first concept was a bridge that would enhance Itsukushima Island more than ever, as well as one that would be established as part of the hometown landscape along with Itsukushima Island.

The second concept was based on the idea that a place is only remembered when actually used by people. In short, proposing a bicycle-pedestrian pathway that would be enjoyable to cross as well as being user-friendly for the local people. Moreover, we wanted to aim at making not merely a road but a new place including bridgehead plazas on either bank.

5. Features of the bridge planning

In order to achieve the design concepts, what we considered important were the bridge plans such as linear shape, bridge length, selection of span length, and structural style. Most especially, something that designers should always keep in mind, based on the idea that planning and designing should be carried out under the most advantageous conditions, we firstly re-examined the conditions given as the reference proposal. After that, the bridge plans went ahead and various bridge styles were considered using 1/1000 scale site models. Here, four characteristics from among the bridge plans are described.

5.1 Reconfiguration of vertical alignment by installing pier-abutments

The first of the given conditions to be paid attention was the vertical alignment of the cross-river bridge. The vertical alignment attaches to the levee crown on the left bank, but on the right bank would be located midair due to the architectural limits of the National Road along the dyke intersecting on the right bank and so could not avoid having a steep slope. This causes the profile of the bridge to be inclined and so we hoped to lower the height of the road surface on the right bank as much as possible. However, according to the given reference plan, the span of the support piers across the right bank is longer than the ones in the river, and so as a result, the girder height of the cross-river bridge would be decided by this section which was an irrational bridge plan.

In order to resolve those problems, we configured the piers on the right bank and partitioned the span length which had been 80m intervals in the original plan to 40m respectively. Incidentally, piers on the bank are called pier-abutment, and the parts which are buried in the bank need a structure to insert casing pipes to prevent dike corruption by the swinging of the piers in times of earthquakes. The structure itself is not particularly difficult, but using pier-abutments needs approval from the river administrators for those reasons described above. However, due to its being competition, consultation with the river administrators was impossible. So, we then investigated existing cases in the Chugoku district, and being assured there were many precedents went ahead using the pier-abutment.

Thanks to that, the road surface of the right bank was lowered from the given plan by 1.5m, and the vertical alignment of the cross-river bridge became nearly symmetrical. Furthermore, as the vertical alignment was lowered, the length of the ramps was shortened accordingly and that reduced the budget (Figure 4).

5.2 Bridge style and selection of span length to enhance Itsukushima Island

Generally speaking, using a symmetrical bridge style for the river would be the most straightforward way, as there is no main flow in the Ota-gawa River Flood Control Channel. However, for the reasons described before, the pier positions of the cross-river bridge cannot be changed and so there would be a maximum of 7 spans.

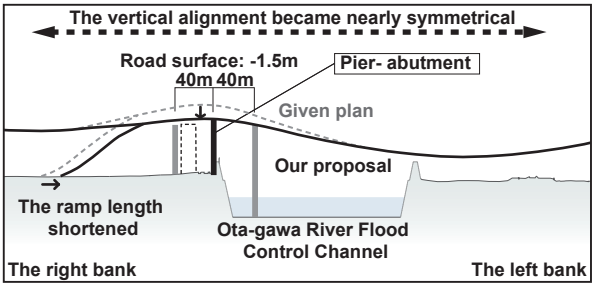

Figure 4 Reconfiguration of vertical alignment by installing pier-abutments

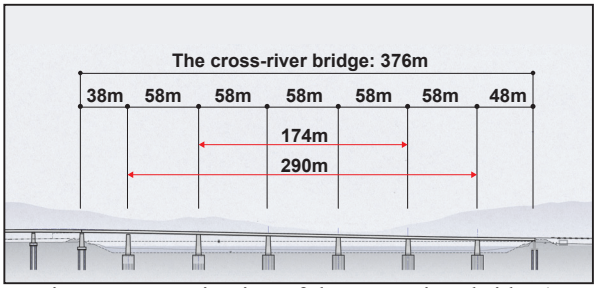

Figure 5 Examination of the cross-river bridge 's selection of span length

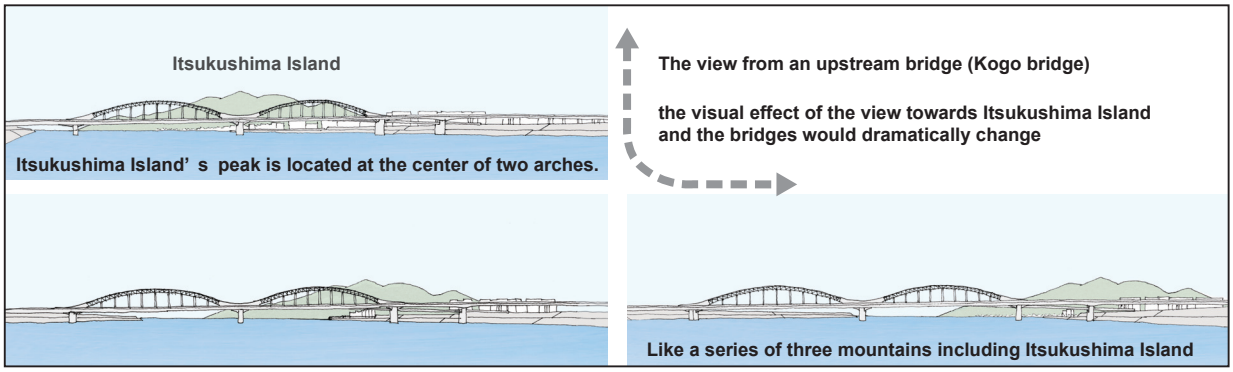

Figure 6 The views from Kougobashi Bridge

Therefore, to make it into a symmetrical bridge style, the choices are either 7 span piers, or 3 or 5 spans having some large structure in the middle (Figure 5). However, to make a bridge to enhance Itsukushima Island, a girder bridge is a little weak, the 3 spans would have a central span of 290m, even 5 spans would be 174m; and it would be easy to imagine it by far overwhelming the scale of the landscape. In addition to that, through experiments using models and our own experiences, the most suitable structural style for the landscape with Itsukushima and the other small islands would be a smooth looking arch structure.

In such a situation, as a result of further studies using sketches that expressed a wider spectrum, we arrived at the idea to take advantage of the fact that the position of Itsukushima Island is slightly off the axis of the river flow. In short, make it like a bipartite arch bridge on a slightly smaller scale than Itsukushima Island, like a series of three mountains including Itsukushima Island when viewed from the Kougobashi Bridge, a typical viewing point upstream. Moreover, with this idea, when crossing Kougobashi Bridge the visual effect of the view towards Itsukushima Island and the bridges would dramatically change, as shown in Figure 6. The view from Kougobashi Bridge is only one example, but thusly an impressive bridge can be created by directing various views where the figure of Itsukushima Island and the bridge are woven together.

5.3 Bicycle-pedestrian pathway alignment from the user's viewpoint

If, like in the given reference plan, the bicycle-pedestrian pathway was aligned at the same height as the expressway and connected to the ground by a slope on the right bank, in order to cross to the other side users would have to climb about 8m, in other words, there would be a 5% inclination for a 250m long slope, apart from

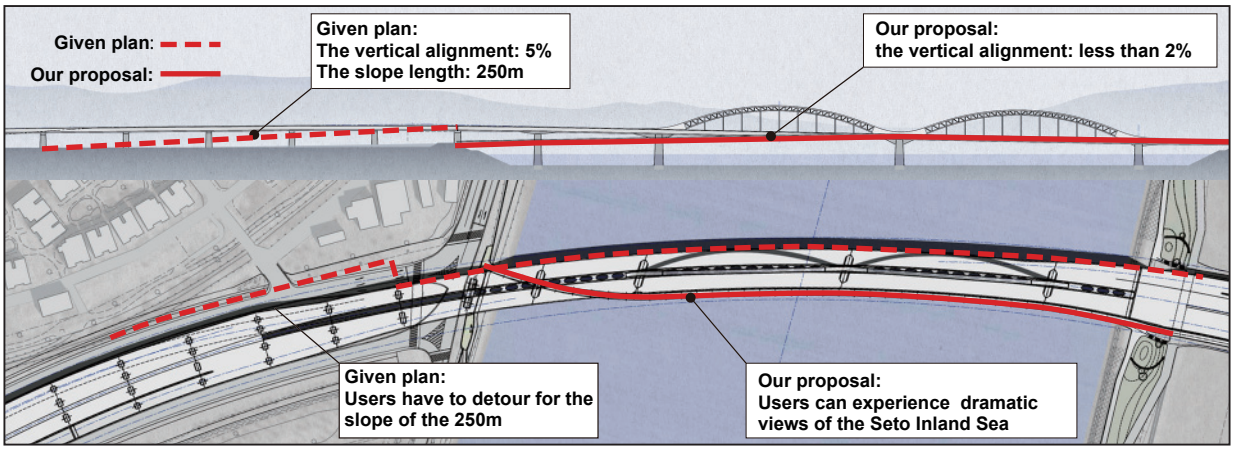

Figure 7 Bicycle-pedestrian pathway alignment from the user's viewpoint

the actual cross-river bridge. This would be too unreasonably tiresome a pathway for pedestrians to use. Although the bicycle-pedestrian pathway was located on the upstream side in the reference plan, it was considered necessary that the view from the bicycle-pedestrian pathway to the Seto Inland Sea needed to be secured as this bridge would be the furthest downstream bridge in the channel.

So, we separated the bicycle-pedestrian pathway from the bridge body midway, and linked it to the banks on either side. By doing this, the vertical alignment became less than 2% so almost flat and in line with universal design. Moreover, the entrance on the right bank is upstream and close to a residential area and from there it clears headway under the main bridge and wraps around to the downstream side, where it leads to a panoramic view down to the sea, a dramatic plan alignment (Figure 7). Still, this proposal was the only one in the six which passed the first selection that suggested alignment of the bicycle-pedestrian pathway links with the banks on either side, and according to the selection result report, this feature was rated highly.

5.4 Continuity of the Ota-gawa River Flood Control Channel Bridge and the west viaduct

We believed that the west viaduct and the on and off ramp bridges were also very important elements. The reason is that generally it is difficult for an elevated bridge to keep its continuity due to changes of road width at the ramps or the intersection conditions of parallel or intersecting roads, and it is necessary to carry out sufficient consideration at the bridge planning stage.

Especially in the case of this viaduct, it was important to plan a bridge that would be compatible with both the following points. The first one is a structural style that sustains continuity with the cross-river bridge, and the second is to choose a standard structure style that can be adapted easily for any further extension of the viaduct in future. Then we chose a PC box girder that could be applied to the same girder height and cross-sectional shape for the whole bridge including the cross-river bridge. The selection of span length on the west viaduct was adjusted to the structure type's standard span length (40m long), and the pier positions of the ramp bridge were aligned to that of the west viaduct.

6. Bridge design

6.1 Design of the cross-river bridge

1) Profile aesthetics

For the arch form, the most important of all the profile silhouettes, the aim was to draw a gently curved line of eternal beauty, and as a result of detailed studies using sketches and models, a curve line with rise ratio of about 1/8 was found to be the most suitable.

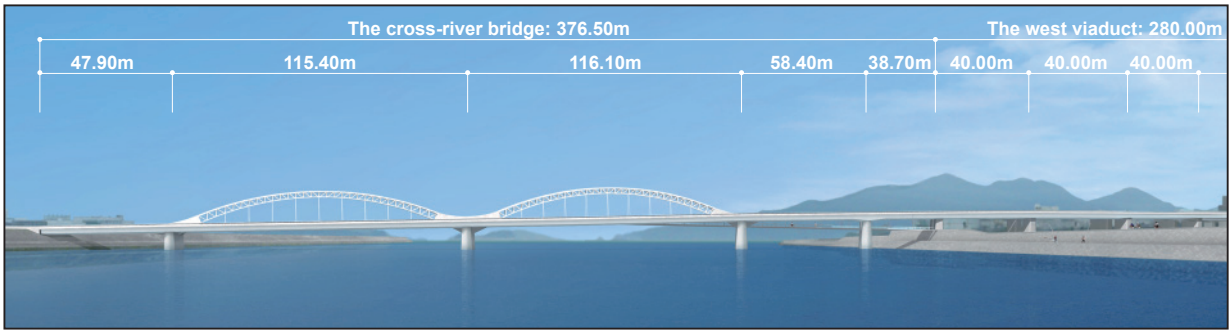

Figure 8 The profile image of the cross-river bridge

Moreover, for the two arches to be three mountains linking to Itsukushima Island, each other's arch should be connected smoothly. On top of that, it is desirable for them to be consistent structurally as well as visually. The reason for that is that a simple structure would make it less manageable maintenance-wise as well as less earthquake-proof, and also having two bearings on the bridge piers would make the pier width wider and the balance of the girders and piers would be lost. The lateral silhouette shown in Figure 8 was realized as a result of careful examination to resolve the structural merits and setting the lateral silhouette from the design point of view.

2) The girder sectional form and pedestrian pathway structure

The sectional form of the bridge is wide at 22.5m, and at the west viaduct where the ramp widens it was necessary to divide it into inbound and outbound lanes with two box girders accommodating the single chord arch main truss in the middle. For the shape of the box girders, we added a symmetrical slow curve at the bottom of the two box girders to give a soft impression as well as a more united look. The overhang of girder height and both ends is 2.5m in order to align with the west viaduct. Oval shaped holes were pierced horizontally into the cross beam linking the two box girders to let the light through to the pedestrian pathway under the girder area and to the surface of the river (Figure 9).

Also, we wanted the cycle-pedestrian pathway that separates from the roadway midway to be as simple and as thin a structure as possible in order to avoid any confused feelings which a double silhouette with the roadway would cause. Precast concrete, which is more rigid than a steel structure and advantageous against vibrations by pedestrians or wind, was chosen for the material. Its support structure is a hanging structure by cables under the main bridge section, and the roadway and the section parallel to it is cantilever structure from the main bridge, and the transition section uses a combination of cable and steel strut (Figure 10).

3) Arch main truss form

There was some concern that if this single chord arch bridge were to be solid rib (box section) that it would be too plain. Yet the truss crossing by pipes that is commonly used as braced-rib has a greater possibility of being unbalanced in the ratio of the thickness of the chord members and diagonal members, and we also thought it would be too difficult to express the attractiveness of the braces. We decided to refine the arch section design policy to give it an edge that enhances its lateral silhouette, showing various expressions depending on viewing distance,

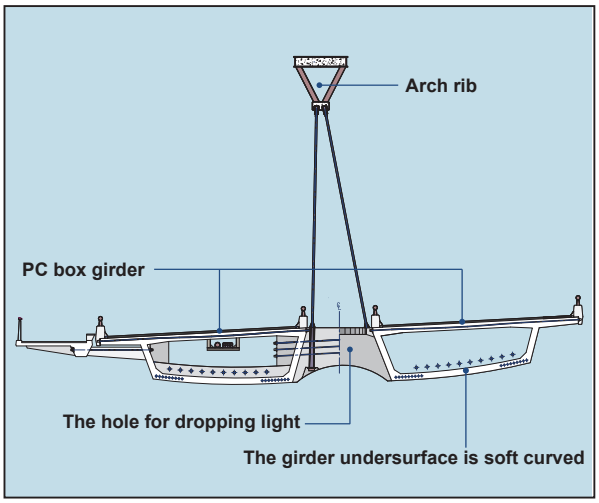

Figure 9 Section of the cross-river bridge

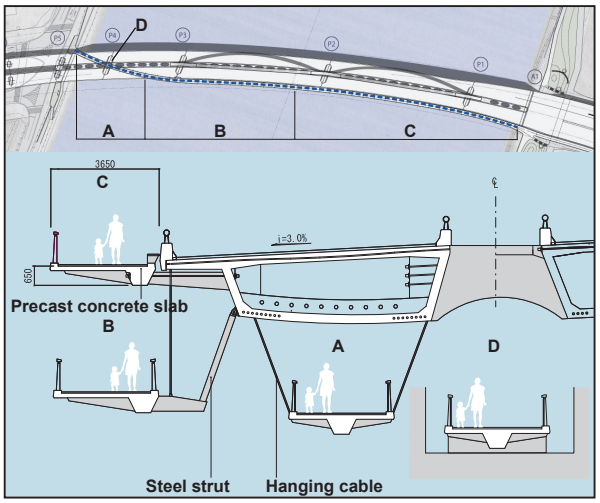

Figure 10 Pedestrian pathway support structure

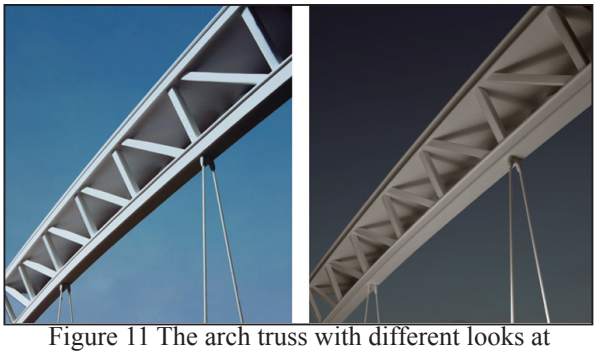

Figure 11 The arch truss with different looks at different times of the day

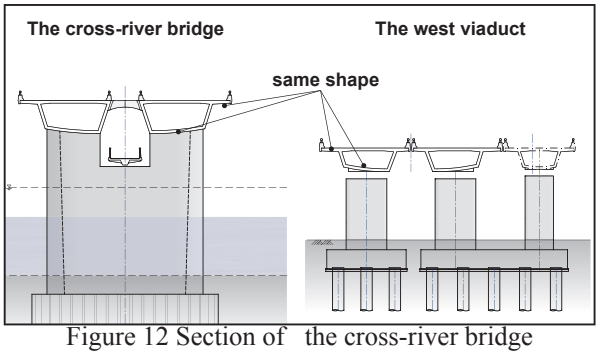

Figure 12 Section of the cross-river bridge and the west viaduct

angle and time. As a result of that, we chose the cross-sectional form that the chord members can express the edge, moreover the required structural section can be ensured by the united box section, and it is the reversed trapezoid braced-ribs that connect them by rectangle diagonal members.

With this cross-sectional form, the diagonal members look embossed in the daylight; conversely, with the lighting at night, the diagonal members are projected onto the plane members creating the effect of having different looks at different times of the day (Figure 11).

4) Pier form

Looking at the lateral silhouette, the arch seems to stretch right to the pier, and in order to make it look as if embracing it fully, the shape makes a reversed trapezoid at right angles to the bridge axis. At the P4 pier where the pedestrian pathway passes we joined the pier and girder firmly without a cross beam in order to avoid giving an oppressive feeling to users (Figure 12).

6.2 Design of the west viaduct

The west viaduct design is, as described in the bridge planning, retaining continuity with the cross-river bridge, and also providing for possible future extension so that the same shape could be applied easily. The detailed design policy is to unite the cross-river bridge and the outer line of the main truss section (depth ratio, overhang, web shape on both ends, pier form), adopt a double supporting beam style and divide the girder section in the wide portion to reduce the oppressive feeling, and thus each respective form was decided (Figure 12).

7. Design of pedestrian space and bridgehead plaza

Along with the bridge design itself, the core of our proposal was to make it user-friendly for the local people, to make the pedestrian spaces and bridgehead plazas on either bank enjoyable to cross and for both banks to function as one united place. For that purpose, together with the bridge planning and bridge design described before, the final plan of the pedestrian space and bridgehead plaza will be explained using the image sketches shown in Figure 13, starting with the right bank.

On the right bank, where the entrance is on the upstream side close to a residential area, we placed a bridgehead plaza that will become a small gathering area, and by making the footpath into a gently curved line, it became a spatial design where it feels only natural to go for a walk (1). Then proceeding to the bright pedestrian pathway

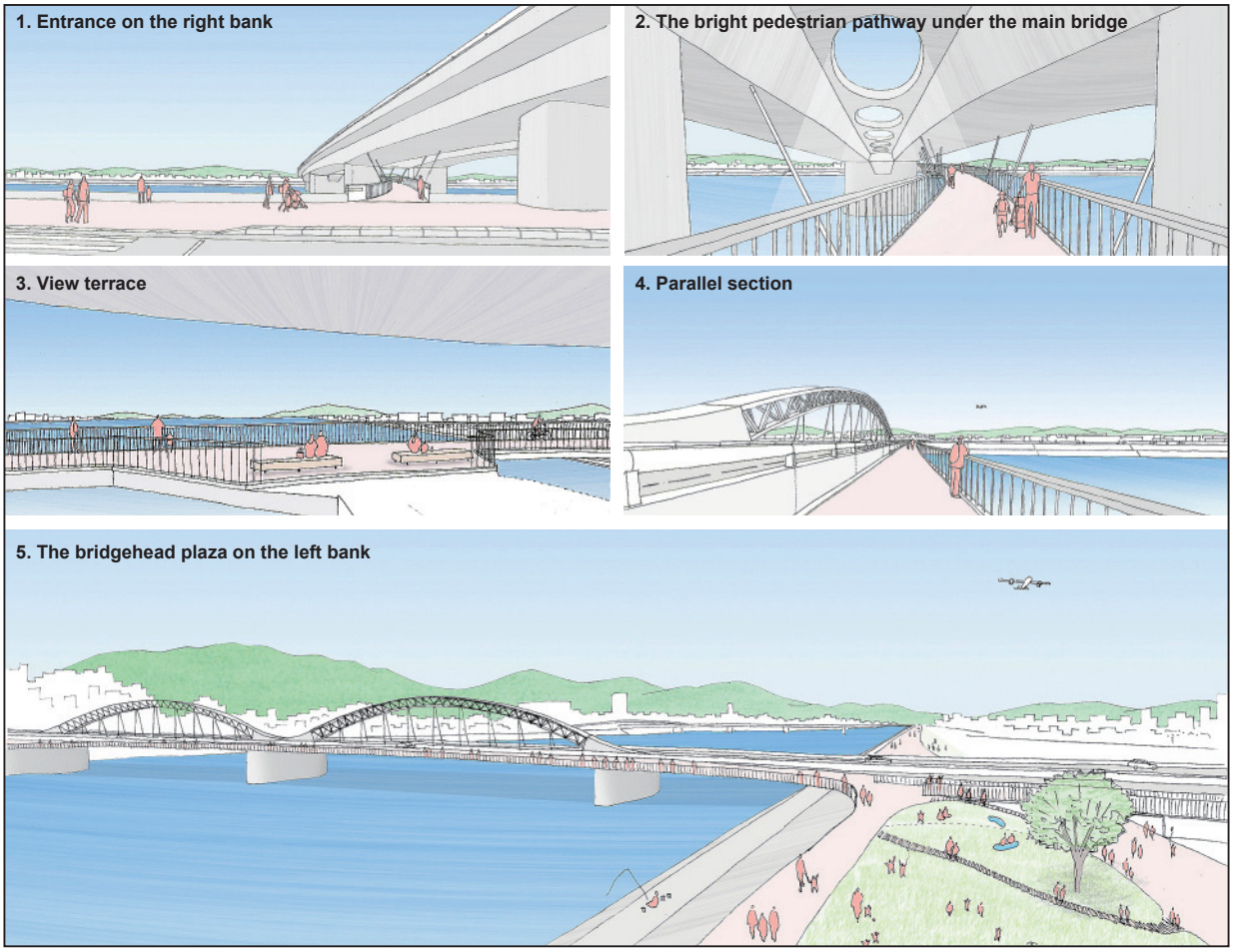

Figure 13 Design of pedestrian space and bridgehead plaza

under the main bridge where light comes through the oval holes in the beam (2) and walking around to the downstream side where the view opens up to the sea, we provide the experience of being impressed by the landscape of the Seto Inland Sea. Here, there is a resting place so that you can view the islands of the Seto Inland Sea at leisure (3). If you keep walking on the pathway, the elevation becomes even with the roadway and you can see the arches on the left-hand side (4). There, the left bank side offers another bridgehead plaza where you can relax and enjoy watching the activity on the bridge or the airplanes (5).

8. Conclusion

Firstly, the characteristics of this design competition can be summarized from the applicant's point of view.

- In this competition, design experts who belonged to an organization different to the applicant were allowed to join in charge of the design or as collaborators.
- At the announcement of the selection results, successful proposals at the "accepted proposal" level or above would have not only the applicant named, but also the design expert or collaborators.
- The applicants of the selected proposal would be contracted for the design work that relates to the proposal plan as well as design management.

Especially, specifying the designer individually and contracting design management can be seen as epoch-

making efforts.

The special features of the authors' proposal are as follows.

- In order to create a new memorable hometown landscape, we proposed a total plan from design concept, to bridge plan, bridge design, and spatial design.
- By taking advantage of the condition of having to use an asymmetrical selection of span length for the flood control channel, a bridge design was proposed that creates a landscape where the bridge and Itsukushima Island, which is very important to local people, interact positively.
- Making the most of the condition that it is an expressway with a pedestrian pathway connected, we proposed a universal design pathway that, by separating the main bridge and pathway, links the banks on both sides at the same time as proposing a spatial design for a bridgehead plaza where those banks function as one united place.
- As for the west viaduct, we adopted standard bridge styles and undertook a study of the designs, then proposed a bridge design that not only ensured the continuity of the cross-river bridge but also allowed for continuity in any future extension of the bridge.

Lastly, we would like to mention again the importance of bridge planning in bridge design. As described before, bridge planning is one stage towards shaping a concept into physical form and any authors' proposal has decisive meaning at this stage. The planning is remarkable as it adds conditions from the aspect of local development treating the bridge site in a wider region beyond the long established conditions. In a country with advances in social infrastructure like the Japan of today, people can no longer be satisfied with mere convenience. Viewed in this way, for bridge design, an approach from the viewpoint of local development is needed along with the importance of the form design itself, and bridge plans incorporating such conditions will be more important in future.

At present, this bridge's detailed design is almost completed as stated in the proposal, and is currently under construction with the aim of finishing by the end of fiscal year 2013. As civic interest in this bridge was very high from the time of the competition, we will be seeking methods to keep citizens and users interested in the process towards its completion, and we would like to make efforts so that the bridge will be loved well.

9. Bibliography

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