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Traditionally Sustainability Analyses of Hydraulic-Architectural Bridge Construction in Iran

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***Abstract*—**Bridge is an architectural symbol in Iran as Badgir (wind catcher); fire temples and arch are vaults are such. Therefore, from the very old ages, construction of bridges in Iran has mixed with architecture, social customs, alms and charity and holiness. Since long ago, from Mad, Achaemenid, Parthian and Sassanid times which construction of bridges got an inseparable relation with social dependency and architecture, based on those dependency bridges and dams got holy names; as Dokhtar castle and Dokhtar bridges were constructed. This method continued even after Islam and whenever Iranians got free from political fights and the immunity of roads were established the bridge construction did also prospered. In ancient times bridge construction passes through it growing and completion process and in Sassanid time in some way it reached to the peak of art and glory; as after Islam especially during 4th. century (Arab calendar) it put behind a period of glory and in Safavid time it reached to an exceptional glory and magnificence by constructing glorious bridges on Zayandeh Roud River in Isfahan.

Having a combined style and changeability into bridge barrier, some of these bridges develop into magnificent constructions. The sustainable structures, mentioned above, are constructed for various reasons as follows: connecting two sides of a river, storing water, controlling floods, using water energy to operate water windmills, making lanes of streams for farms' use, and building recreational places for people, etc. These studies carried in bridges reveals the fact that in construction and designing mentioned above, lots of technological factors have been taken into consideration such as exceeding floods in the rives, hydraulic and hydrology of the rivers and bridges, geology, foundation, structure, construction material, and adopting appropriate executing methods, all of which are being analyzed in this article.

***Keywords*—**Hydraulic-Architectural Bridge, Sustainability, Construction

I. Introduction

BRIDGE construction on rivers and valleys connects different regions and as a result the relation between human societies is facilitated. This civil move whose bases were put on simple and primary stuff, in its maturity process and outbreak of engineering creativity, from the old ages till now has lead to construction of immanent buildings and different cultural and ancient heritages all over the world.

Engineering and architecture of Iran has been so much consonant and companion to quadruplet ingredients (fire, wind, water and soil). The soil; which is the main element of architecture has made original architectural spaces in different shapes and forms such as arch, vault, and walls [1].

II. Shadorvan Bridge Barrier (Dam Blocker)

In most cases barrier (dam) acts the same as bridge and its invention and construction is contemporary to bridge construction. The barriers which Achaemenid established on guts and rivers like Sivand Barrier which is thought to be built in Cyrus time and Amir Barrier near Marvdasht has played the role of bridge. The established Shadorvans on the rivers had the function of bridges and in contrast to barriers which collected water behind them, they spread water and in addition to functionality in transportation they were used as promenades. Among the most important samples we can name Shoushtar Shadorvan and the most beautiful one in Iran and maybe in the world are Khajou and Allah Verdi Khan Bridges in Isfahan [2]. As it is famous the flower ceremony in Nowrouz and water ceremony in Safavid times were celebrated on these bridges and beyond any doubt the role of Shadorvan is the question.

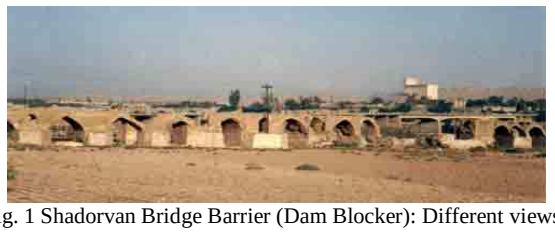

Fig. 1 Shadorvan Bridge Barrier (Dam Blocker): Different views from dam blocker

Fig. 2 Shadorvan Dam Blocker: View from dam location over Shatit River, Khuzestan Province, Iran

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III. UTILIZATION OF DURABLE MATERIALS

The effective element on durability of bridges in Iran is using lime mortar especially in bases and between the bases of bridges. At least from one thousand years before Christ, Iranian knew lime concrete and used it in building construction. Greek learnt lime burning from Iranian, Romans learnt from Greek and Europeans learn from Romans. Therefore Iranians can be considered as important pioneers in creating lime mortar in architectural constructions. For the degree of durability and strength of lime mortar, very soon Iranians used lime concrete which is a suitable hydraulic mortar in constructing bridges. Another point is that Iranian also acknowledged gypsum burning and plaster work very soon. Parthian time cornice clearly shows this matter. In Iran vaulting by bonding with big bolster technique was done by using quick setting plaster mortar (like 26 meter bolster of Miyaneh, Pol Dokhtar). Using plaster, lime mortar, cement grout, dressed stones and finally brick helped the durability of bridges in first periods of bridge construction. Therefore, the bridges with high durability and long life got a significant insolubility against different factors of destruction [3].

IV. METHODS OF BRIDGE CONSTRUCTION

From ancient times Iranian experts have used different methods for constructing bases, arches and determining location of bridges. Bridge constructors' main effort was to stabilize bridge bases where the river water was less. Since deepening water and as a result constructing foundation under water was not possible, the foundation were constructed in less deep but massive spaces to avoid the displacement of foundation by running water. In constructing arch which were mainly four center arches uniform methods were used; therefore, Iranian experts build the constructions without using framework. In contrast to Romans, they also did not use frame work in constructing bridge arches, but constructed them with plaster mortar and brick using bonding method and between multiple arches of the bridge bonded to each other with brick partitions. However they used cement grout was also used in foundation and walls. Apart from quick setting aerial mortar (plaster mortar) and lime cement mortar for humidity insulation, Iranians had also devised regulated set cement mortar as well. By using albumen and living lime powder (CaO) they made mortars which were more durable, quickly settled and stable in water. Because, living lime powder (CaO) with albumen gives slaked lime (Ca(OH)2) and 275 calories of heat is freed from it. The freed heat cooks albumen and a very durable mortar is created; even now the mortar of living lime powder (CaO) and albumen is used for tinkering china portions [4]. In constructing big bridges on surging rivers, Iranian used different techniques which were difficult and strange. As in constructing a bridge in Ghafghaz port (Babol Abvab) for not being able to restrain the power of surging water, they constructed the bridge base as explained: The skin of big beasts like cow, camel and donkey were blown with air and were bind beside each other; on the blown skins frame works of beam and wood are created and the skins are fastened under them. The framework, then, thrown into water and was carried where the bridge were to be constructed and it was restrained from river coast to prevent its moving by water waves.

The base of bridge were constructed on floating framework; once the base of bridges became heavier the framework sank into water and the restraining thread loosened till the blown skins sat on river floor; the structure of bridge base were brought up the water as much as it was needed. The divers then were sent under the water to incise the skins and let the air out of them and the framework be set in river floor. This traditional method is a kind of foundation construction using compressed air which was matured in later periods. It is said those foundations of Siose Pol (33 Bridge) and Marnan Bridge in Isfahan is constructed as follows: When the water was shallow the gully of water was skewed from where the bridge base was to be constructed. The space where foundation had to be constructed was excavated 4 to 5 meters from river floor where the iron bridge foundations were built on it. On this layer, in foundation level, big clay columns are set beside each other and the holes of clay columns are tinkered by clay puddle mortar, lime concrete and lighting oil. After the lime concrete is set, the foundation was constructed on clay columns. The bridges of bad soils which are remained from old ages are those which were constructed on stone basin of river such as: Shahrestan Bridge in Isfahan, Pol Dokhtar in Molavi gut Gavmishan Bridge between Jaider and Simreh constructed on limestone, Dezful Bridge constructed on Marj (a land with very high borders) and Shoushtar Shadorvan which was constructed on sandstone [5].

V. SHAPE OF PIERS AND HYDRAULIC EFFECT OF WATER

The structure of foundation and historical bridge piers indicates the fact that their sustainable design was based on both the architectural and structural methods and that among these procedures, water resistance factor against the river's water pressure had been regarded more than the other ones. Some important structural factors concerning the resistance and sustainability of the bridge against water pressure include: a) considerable weight of bridge; b) connection surface of the bridge to the riverbed; c) the shape of bridge pier which acts effectively in absorbing force.

In general, the shape of the pier is in such a way that they are given a performance similar to breakwater. The form of breakwater causes a decrease in the dynamic force to the bridge preventing from water-flow turbulence (in lower parts of pier or foundation). The shape of frontal pier and foundation are divided in three groups with regard to the absorption amount of dynamic force of water [6]:

1) The form where the frontal part or pier has no angle and the absorption of dynamic force of water is high (figure3).

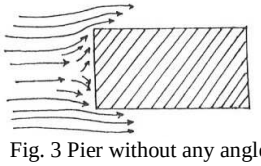

Fig. 3 Pier without any angle

2) The form where frontal foundation or the pier itself is curved and dynamic-absorbing power is more or less low (figure4).

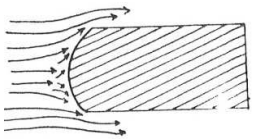

Fig. 4 Pier with Curved form

3) The form where the frontal foundation or the pier itself has a sharp-point pier or foundation frontal and the absorption dynamic force of water gets low (figure5).

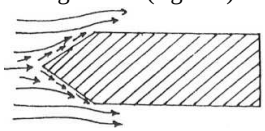

Fig. 5 Pier with sharp-point form

A. Various Traditional-Sustainable Forms of Pier and Bridge Foundation in Iran

The shape of pier and foundation is classified into 6 forms in sustainable historical bridges in Iran [7]:

1) The sharp point and angled piers and foundations with the form of breakwater such as Shadorvan bridge barrier, Dezful bridge barrier, Juei and Khajou bridges in Isfahan (figure 6).

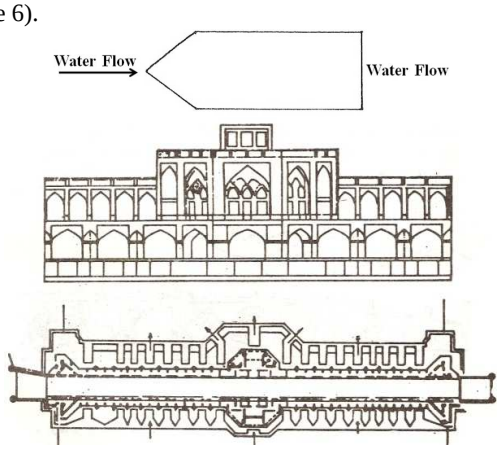

Fig. 6 Sharp point angled piers (breakwater forms), Khajou Bridge, Isfahan.

2) The curved piers and foundations with the form of curved breakwater such as Varzaneh and Allahverdikhan bridges in Isfahan (figure7).

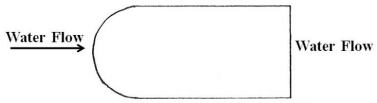

Fig. 7 Curved form pier

3) The sharp point and angled piers and foundations in both ends with the form of breakwater in both ends such as Abbasilar Bridge and Pol Dokhtar in Zanjan (figure8).

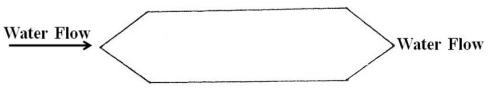

Fig. 8 Sharp point and angled piers in both ends

4) The curved piers and foundations in both ends with the form of breakwater in both ends like Marnan and Shahrestan bridges in Isfahan (figure9).

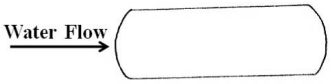

Fig. 9 Curved pier forms in both ends

5) The sharp point and angled piers and foundations with breakwater in two opposite directions of water flow and curved in other side, such as one in Baba Mahmoud Bridge in Isfahan (figure10).

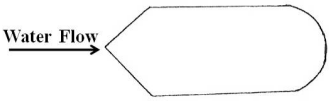

Fig. 10 Curved pier forms in both ends

6) The piers and foundations with no form of breakwater in two upper and lower sides, such as Kaj Bridge and Gharb Bridge in Tabriz (figure11).

Fig. 11 Pier without breakwater form

VI. Shape of Piers and Hydraulic Effect of Water

Considering combining bridge spaces, the two categories of functional and promenade bridges should be clarified.

The first group includes traffic bridges; the bridge space includes a stone passing way with short ramps. In Shahrestan bridge of Isfahan classified as of this group, there is a half-roofed and half-open space in one side of the bridge which seems its function is to control traffic on the bridge. Regarding their role and function in urban life, the second group includes diverse space combination. This group is designed for three different activities, and depending on each activity the bridge is designed in a special shape having a different space [8].

A. Traffic

Among the main functions of the bridge are the traffic travel and pedestrian walk on them. The special traffic spaces of the bridges are open spaces, mainly the middle part of the bridges.

B. Recreation

The function of the marginal parts is amusing the pedestrians and is designed as half-opened spaces. Since people stood on Zayanderoud Bridge to watch different ceremonies conducted on Zayanderoud water, the marginal parts have got special forms. In Khajou Bridge this form is in the shape of half-octagon that is extending out of the bridge in three points and create a half-open and half-roofed space for temporary stopover. In Jouei Bridge, the stopover is also in half-octagon form extending out of bridge in the middle part, underneath of which is a half-open and half-roofed space.

In Siosepol Bridge, the half-open and half-roofed spaces extending out of the bridge suit this objective [9].

C. Spending Pastime and Having Close Access to Water

Closer access to water and enjoying the fresh air in such surrounding is a fun and refreshing activity. Devising slabs on water and small spaces under the springs of the bridge in Siosepol creates some half-open spaces fulfilling purpose mentioned above. This part can be used as a pathway as well. The parts underneath Khajou Bridge extended out in stair shape can be used for the same purpose.

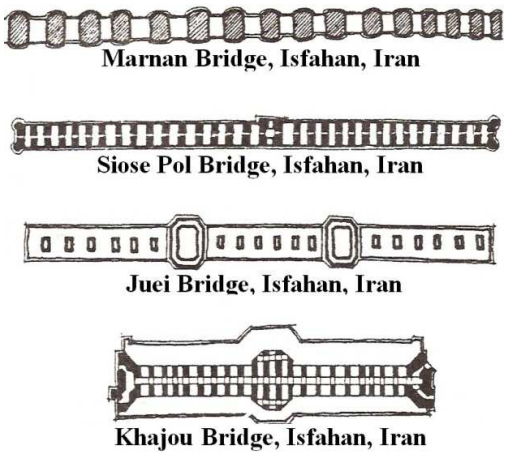

Fig. 12 Construction method- Space composition around exterior open spaces

Iranians have combined worship of water with bridge construction and to pass through it (without making it dirty) and union the two sides of rivers and deep valleys they have constructed bridges by stuff of their own regions. The shape and symbol of arch bridges of Iran were transfigured in fire temples and then in brick arches.

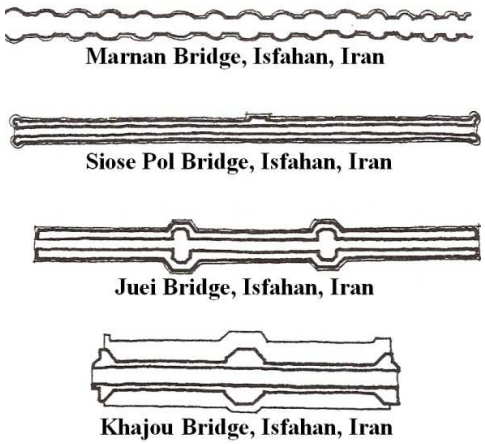

Fig. 13 the alignment between inner and outdoor spaces

When it was decided that Chahar Bagh be connected to other side of Zayandeh Roud River to respect four season, it could not take distance from growing architecture; the magnificence of Chahar Bagh and aesthetic peace of its time.

So it had to transfer and take with it all these art, beauty and architecture to the other side of river. Therefore, Siose Pol takes with it the magnificence of Chahar Bagh and Pole Khajou is the carrier of stillness and glory of Naghsh-e-Jahan, Shah Mosque, Chehel Sotun and Gheisariyeh Baazar of Isfahan with a praising harmony [10].

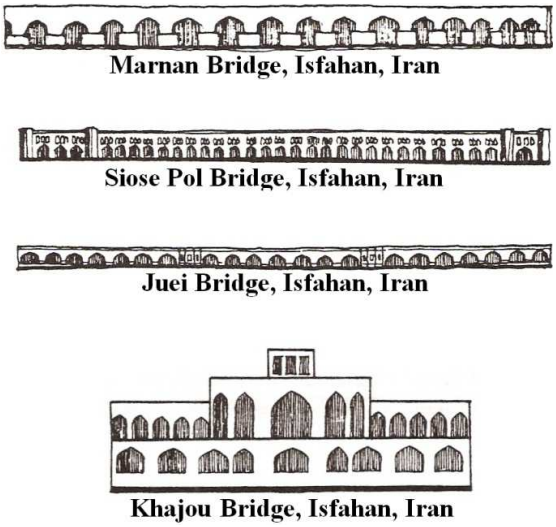

Fig. 14 Placement of spaces in the facade

VII. Conclusion

To put it in the nutshell, the items and principles below were considered in construction of sustainable and traditional bridges in Iran:

a) Using simple shapes for the bridges with particular traffic function and composite shapes for the bridges which were part of city space. The composite shape is obtained by combining simple geometrical shapes such as square, rectangle and octagon.

b) Making separate pathways for vehicles, pedestrians and stopover.

c) Use of high surrounding walls to create an enclosed space for traffic move.

d) Making roofed pathways and spaces for stopover and resting places.

e) Using underneath part of the bridge and devising spaces and pathways to directly access water.

On the one hand, bridge is an element of urban axis and a part of it and can be used as a factor to change the speed of water flow and create waterfalls. Some bridges do not act only as a traffic travel space and are designed in the form of urban-life spaces; however, the possibility of direct access to water and creation of close relationship with water flow make the water be the important element in the design of city space.

Bridges are designed to be used for diverse functions or an amalgamation of them. Employing half-open or half-roofed spaces creates different spaces with different functions, but the sustainable design of Iranian bridges is based on the items mentioned as follows:

a) Makes increased use of desired wind and hinders undesirable ones to facilitate pedestrian walk on the bridge.

b) With structural schemes , the surrounding space can be used symbolically (changing rivers to lakes by blocking water flow in Khajou Bridge, the mirror-like role function of water and its concept).

c) Make the best of water flow especially its music.

d) Making it possible to look at nice views of surrounding green landscape.

e) The bridge is designed in a way that the river should cross vertically so that the current of water would be under control, subsequently making it possible to play with it.

This article aimed to study and examine Iran's traditional bridges approaching sustainability which has especial place as one of the architectural symbols in history and culture of this land and expresses the capabilities of Iranian in different centuries of history and the consistency and maturity of a kind of art and architecture. During recent centuries the construction of bridges had a significant progress and gradually vaulted bridges of stone stuff were constructed for any other kinds of bridges. Later on by the invention of cement and making concrete, this saving and durable material of construction, the structure of concrete and iron vaulted bridges progressed even more by using steel and iron cabals. From nineteenth century the idea of simultaneous use of concrete and steel (ferroconcrete) for construction of bridges rapidly grew in Europe. New bridges of the time are constructed by steel and concrete and their hundreds of meters bolsters change the deep and vast valleys into smooth ways for heavy transport vehicles.

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