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Retrofitting the Old Bridge of Dezful

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ABSTRACT

The objective of the study is the proposing of a method for the retrofitting of the structure of the old bridge in the city of Dezful using a descriptive analytical approach. In order to develop such an approach a vast library research was conducted and various resources reviewed. The old bridge of Dezful is one of the few remaining ancient structures in existence which was constructed in the late Sassanid era and which reflects the local and traditional forms of the city. Using local materials, the ancient architects of the bridge have sought to create an aesthetic and durable structure which has remained in place after more than 1,700 years. The focus of the study is however on the retrofitting of this ancient structure in the city of Dezful and the sustaining of it for future generations of architectural engineers.

KEY WORDS: Traditional architecture; retrofitting; the old bridge; the city of Dezful

1. INTRODUCTION

Among one of the historical structures in Iran with a history spanning 1,700 years is the bridge at Dezful which was constructed towards the end of the Sassanid period during the reign of Shappur I using dressed stone , mortar and is some places baked clay brick .The bridge consists of 14 original arches; 13 arcs and 3 contemporary concrete arches. Some of the pedestals of the bridge are also related to more contemporary eras. The bridge consists of 20 pedestals which operated as water ways. The maximum height of the structure is 10 meters; with a deck width of six meters, and it is approximately 350 meters in length. The satellite images below show the position of the old bridge of Dezful across the Dezriver.

Fig.1 Satellite image of the old bridge of Dezful (source Google)

Fig. 2 Cadaster image of the old bridge of Dezfulcira 1956 (National Heritage archives)

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Historians and Researchers have unanimously agreed that the construction of the bridge is related to the Sassanid period and most attribute the building of this weir-bridge as concurrent with the founding of the city of Dezful. The bridge has been repetitively damaged as a result of the massive floods which have occured on the Dezriver.

Background of the Study:

In various books and articles the city and its bridge have been mentioned . Among these manuscripts one can refer to the“ Restoration and Rehabilitation of the old bridge of Dezful” by Dez Ab Consulting Engineering Company,2013.

METHODOLOGY

The current study has been carried out using a descriptive analysis method. The collection of evidence and materials (such as books and articles) by the authors were done using library research and field surveys(pictorial evidence and documentation) .

2. Field Survey

The field survey of the old bridge of Dezful indicated that the bridge had been constructed with stone and mortar and in some zones with baked clay brick. The bridge consist of 14 main arches, 13 arcs and three contemporary concrete arches . Several of the bridge 's pedestals were constructed more recently. The Bridge has twenty pedestals which were once used as waterways .The weir bridge was at its highest point 10 meters high with a total span of 6 meters and approximately 350 meters in length. Due to the importance and function of the bridge , it has been repaired and refurbished over various periods and a lot of attention was given to the retaining of its original proportionality and superficial symmetry so that it would remain sturdy and steadfast. The Bridge was completely refurbished during the rule of Azadollah Daylami and during the Saffavid era. Due to a severe flood in the late Ghajar era, part of the bridge's arches and pedestals were swept away. In the 1940's and as per a royal decree by Pahlavi I, the damaged section of the bridge was repaired by German engineers. The German engineers used reinforced concrete and three jointed arches, with pedestal distances of 30 to 40 meters spacing respectively even though the original pedestal foundations remained intact.

The figure below illustrates the general view of the old bridge's arrangement. The model has been scaled on the basis of the measurements and pictures taken. Due to the sequential arrangement of the bridge's architectural features and in order to be able to easily identify the various components the pedestals are marked with an A, the arches with a B the arcs with a C.

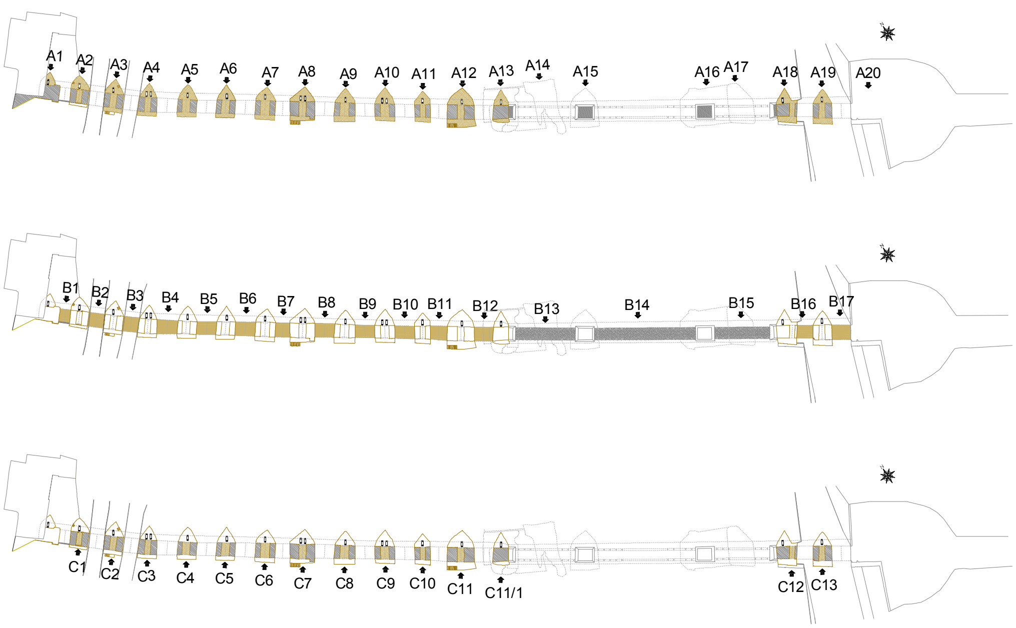


Fig. 3 The arrangement of pedestals, arches and arcs in the old bridge of Dezful (source Dez Ab, 2011)

The general structure of the bridge is the irregular arrangement of foundation stones which are established upon the bedrock of the river bed and which continue up to the level of the water in the river. The pedestals are then constructed on these foundation stones in the form of dressed stone which are reinforced with lead joints which at present do not exist and only the boreholes and gimlet holes can be observed in the structure. The pedestals have been constructed to the highest probable level of the river at flood level. The main fired clay brick arches and arcs are then formed upon these pedestals, after which the abode brick walls have been constructed and the space between them has been filled with silted earth. The deck of the bridge was paved and the shelters added on it.

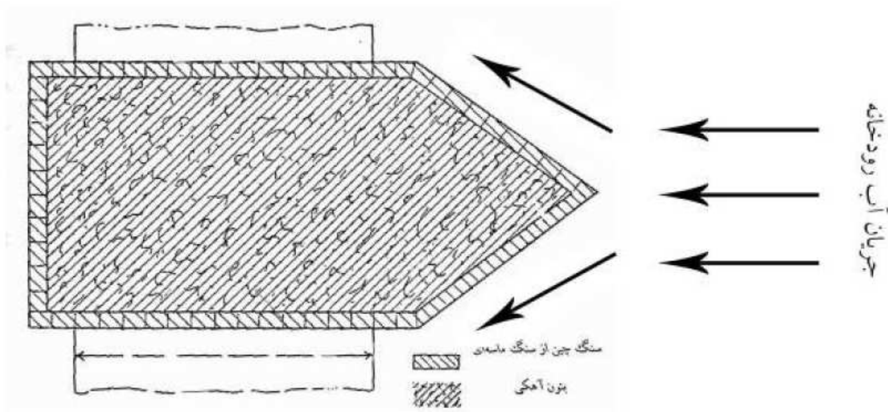


Fig. 4 Cross section of one of the bridge pedestals with flow breaker (stabilizer)

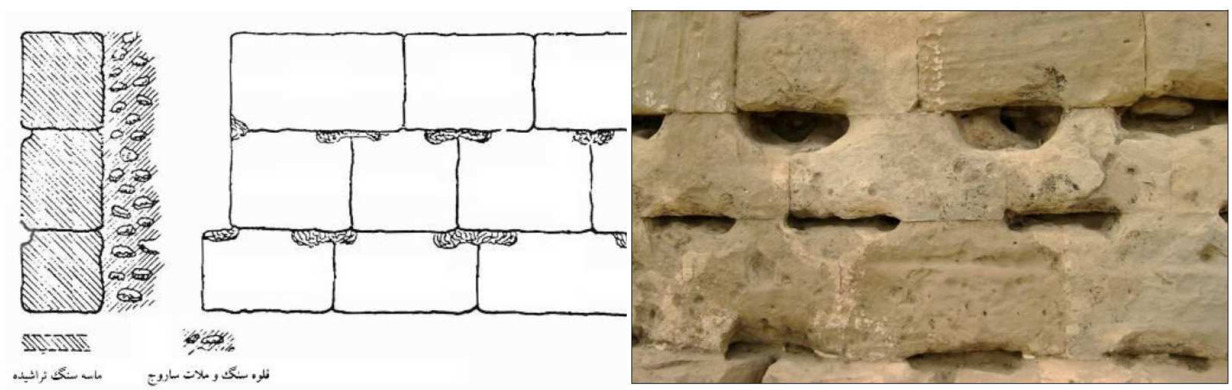


Fig. 5 The structure of the Remaining pedestals showing the dressed layers

Table 1: Technical specifications of the materials used in the bridge construction

Type of material	Resilient module GPa	Pavason rate	Specific weight t/m^3
Foundation material	0.25	0.15	1.9
Pedestals	1.54	0.2	2.0
Brick arches	0.24	0.11	1.8

2.1. Causes of Damage to Structure

Since the construction of the old bridge of Dezful (over 1,700 years ago), it has suffered damage and multiple structural problems. Some of the damage can be attributed to natural causes (such as seasonal floods; torrential rains and so forth) while other types of damage are due to human interference and activities in the region. In recent years, the construction of the Dez reservoir dam and reregulating dam upstream of the bridge has greatly reduced the occurrence of the massive floods which used to flow through the river and has controlled the current flow rate of the river ,thus negating any future damage due to floods to this structure. The main causes for the damages to the old bridge of Dezful can be classified into the following categories:

a) Damages inflicted to the structure prior to 2011

1. The breaking of the weir during the post Islamic period for the providing of water for open canal irrigation systems

2. The destruction of part of the bridge , the guard towers and two columns by the people's council and the British council in the city of Dezful during WW I
3. The construction of three reinforced concrete arches by a Swedish Engineering company named Santop in 1937
4. Some damage was inflicted by the impact of missiles to zones near the bridge during the Iraq-Iran war.
5. The adding of a pedestrian pathway upon the bridge resulted into the supports being added towards the flow breakers of the bridge.
6. Squatters settled in the arches at the beginning of the bridge and contributed to its defacement.
7. The walling up of some of the smaller stream aqueducts and arcs with concrete blocks.
8. The constructing of a riverside motorway passing beneath the pedestals of the old bridge and the damages due to car accidents and crashes into the pedestals in recent years which is probably the most crucial problem to date.

b) Damages inflicted to the old bridge after 2011

1. Unregulated remedial work on the superstructure and understructure of the bridge
2. Lack of accuracy and craftsmanship in the repairing and refurbishment of the arches ; arcs ; flow breakers and structure of the bridge.
3. The passing of vehicles under the bridge
4. Damages inflicted when tearing down the added contemporary structures.
5. Inefficiency of the runoff water systems for the disposing of surface water on the bridge and under the bridge.
6. The irregularity of the plaster applied on walls throughout the structure.
7. Natural and environmental causes
8. Lack of efficiency in the retaining of the cleanliness and maintenance of the bridge.
9. The planting of trees adjacent to the pedestals of the bridge and the growth of vegetation on the bridge and its pedestals in Spring.

These damages have been illustrated in fig. 6 to fig. 23

Fig. 6 Installing of a steel structure on the flow breaker(2015)

Fig. 7 Cement covering on historical brick (2015)

Fig. 8 Wall added to the flow breaker (2015)

Fig. 9 The crumbling of the filling between the bricks and poor plastering (2015)

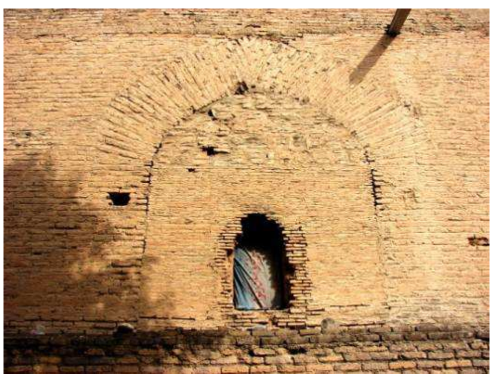


fig. 10 The closing off of the Northern exit of the aqueduct (2015)

fig. 12 The irregularity of the materials and masonry used(2015)

fig. 11 Cracking along the arch joints (2015)

fig. 13 Cracking along the arch joints (2015)

fig. 14 Separation between stone masonry and clay bricks (2015)

fig. 15 Empty boreholes which were filled with lead clamps

fig. 16 Cement covering with a brick design over the pedestal (2015)

fig. 17 Damage due to the malfunctioning of the water conduit(2015)

fig. 18 collapse of the upper part of an arch (2015)

fig. 19 Destruction of the lower foundation stones (2015)

fig. 20 Destruction of the access stairway from the aqueduct to the crest

fig.22 Destruction of the arch foundations (2015)

fig. 21 Destruction of the steps(2015)

fig. 23 Deep crack in foundation (2015)

2.2. Repairs and Refurbishment Carried out

Among the various historical structures in existence, bridges have had a very important position and were considered as strategic corridors. The passage of time, the effects of natural events (floods and earthquakes) and man made elements all effect such bridges and this is reflected in the state of repairs and refurbishments, based on the availability of technology and funds, on such structures over time. In this particular case the use of a variety of bricks and various masonry materials in different parts of the structure show the eras where the repairs and refurbishment were made. Some of the most common are illustrated in the figures below. These repairs were carried out on the arches, pedestals; triangular flow breakers and the rectangular abutments behind the pedestals. The tensile stress imposed upon the arches of the bridge are mostly due to the erosion of the building materials or external forces acting upon the resistance of the structure which in turn have resulted into tensile stress cracking or localized crumbling of material. Based on the extent of the damage, repairs have been carried out using abode brick; wooden supports; or plastering. The cracks in the arches have been plastered over with cement. With the crumbling of the overlaying plaster and eroded parts in various places of the structure, one may observe that repairs have been continuously carried out in contemporary decades. Boreholes made in parts of the pedestals and arches show that lattice scaffolding was used and secured accordingly during the repairs. (fig.24 to 26)

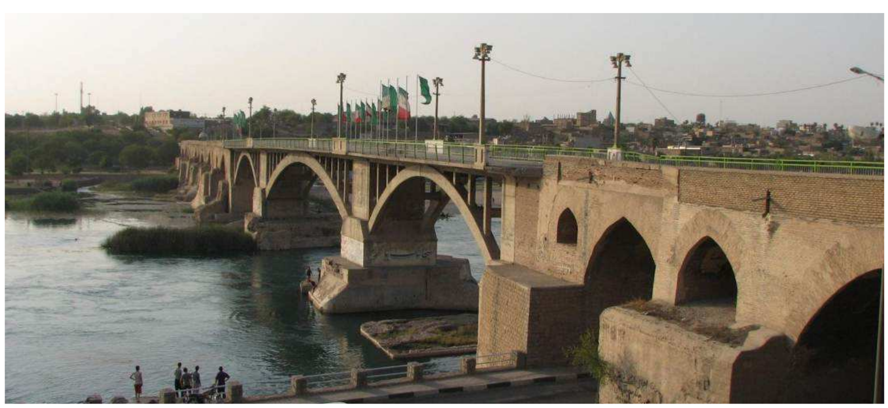


Fig. 24: View of the old Bridge of Dezful from the Eastern bank (2015)

Fig. 25: Application of cement plastering to cover arch cracking (2015)

Fig. 27: Remains of scaffolding used for the repairing of the Structure over various periods (source the author-2014)

Fig. 26: Repairing of arch using abode brick and cement plastering in recent decades (2015)

Fig. 28: Remains of scaffolding used for the repairing of the Structure(source the author-2014)

As can be seen in picture 28, in order to decrease the development of the radial cracking in the crown of the arch, wooden supports were utilized. Continuous surface repairs and occasionally major repairs on the pedestals of the bridge had been carried out due to the erosion which had occurred as a result of myriad floods . Picture 27 shows that the repairs occurred over different periods. The repairs whether carried out on the basis of standards or haphazardly have all added to the complexity of the structure's behavior.

3. The strengthening of the Bridge-Wier

3.1. Components and Targeted Structures

Taking the problems of the of the structure into account and the observing of the objectives and approaches to the strengthening of the Dez wier- structure, the applicable scenarios were categorized on the basis of the various components. The targeted components for the weir-bridge are:

- The spans and alcoves
- The ancillary walls of the structure
- The arches of the brick structures
- The foundation stones for the arches and the central pedestal
- Foundation and substructure

3.2. Applicable methods based on the need for Strengthening

3.2.1. The Bridge Deck

The problems and main defects of the bridge's deck were determined based on the qualitative and quantitative evaluation carried out. The main requirements were determined as:

- Caulking and the dispersing of surface water
- Resistance against the wear and tear of traffic
- Resistance against environmental elements and the extending of the life span of the bridge
- Decreasing and minimizing the number of seams

- Maximizing the amount of energy absorbed

Weight Unloading
The deck of any bridge should be built of durable materials to withstand the erosion resulting from the extent of traffic on the bridge, the draining of rainwater and climate changes. In addition it should be able to safely and effectively distribute the loads imposed upon it to the underlying arches and subsequently the pedestals beneath itself. One method of doing so is the utilizing of thin reinforced concrete slabs (Fr.dalle') since the use of unreinforced material is not effective in the transferring of the weight of the traffic upon the deck of the bridge to the crown of the arch. Using modern architectural techniques or using a thin covering of stone material over the reinforced concrete slab, it is possible to retain the appearance of the deck. It is believed that the best paving material for the deck would be a polymer composite concrete covering. This will be further elaborated on below.

3.2.2. The Lateral walls of the Bridge

The qualitative and qualitative analysis of the structure have indicated that the lateral walls are suffering from structural problems (as per the figure below).In this regards the following solutions have been presented:

- Reducing the tensile stress at the base of the wall.
- General cross section stabilization
- Reducing the relative deformation between the crown and the haunches.
- Flexural stabilizing of the external arch sheeting

Taking the aforementioned into account the most appropriate solution proposed would be the flexural stabilization of the lateral walls and the designing of a harness to join and balance out both walls.

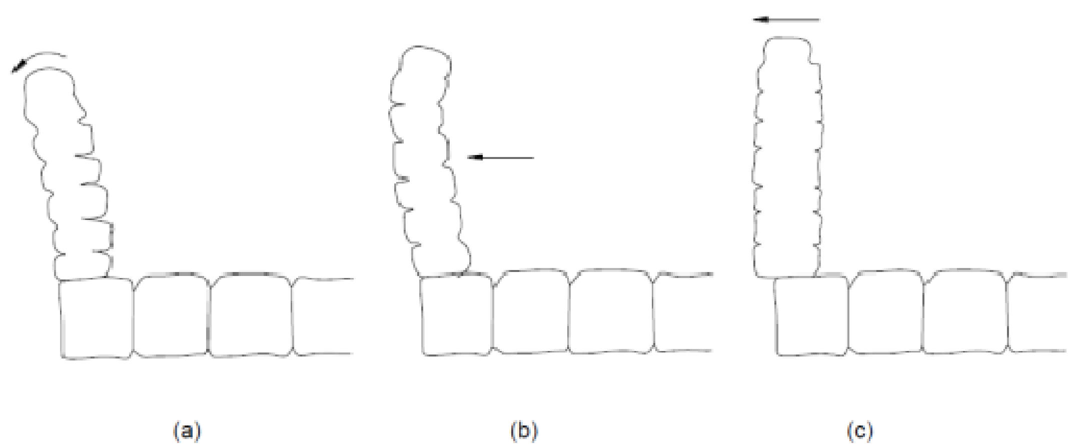


Fig 29: The damage modes and main problems of the haunches (source Dez Ab co. 2011)

3.2.3. The Brick Arches of the Bridge

The qualitative and qualitative analysis of the structure displayed the problems existent in the clay brick arches of the structure and the current needs have been categorized as follows:

- Controlling the tensile stress
- Controlling the shear stress
- Durability in terms of environmental and extending the operational lifespan.
- Increasing the capacity to absorb energy.

During seismic loading and traffic loading, a great deal of stress is imposed on a structure which is often greater than the resistance of the materials. The following solutions are proposed for the controlling of the problems:

- Creating arch frames or the use of external steel or concrete reinforcement
- The extracting of the filling material used in the arches and the refilling with lighter material.
- The use of reinforced concrete slabs on the deck for the transferring of the perpendicular load to the haunches and the foundation.

- Using internal reinforced concrete arches for the transferring of the perpendicular load to the haunches and the foundation.
- Reinforcing the pedestals and the preventing of transferring the seismic load of the pedestals and deck to the arches.
- Surface reinforcement using cable , FRP or steel rods
- Subsurface reinforcement
- Grouting using upgraded mortar.

These solutions have not been proposed on the basis of historical and architectural reasons. It is believed that the best solution for arch reinforcement in this particular case is the utilizing of sub structural reinforcement .In this method by creating regular groves and embedding the reinforcement rebars, the necessary reinforcement for flexural, shear and tensile stress and the controlling of cracking will be provided; what more, once embedded, the reinforcing rebars are covered with a suitable coating material which will also be used to cover the existing cracks also. The reinforcing rebars should have the same structural density of the materials used in the structure, thus not just any type of steel rebar or FRP can be used. In addition the grouting material used must have the same combination and density of the existing filling material in as such that it would be compatible both in terms of its chemical and physical composition to the whole structure. The type of rebar used for stone and clay brick structures varies in extent, but it has been applied widely on a global scale for the restoration and refurbishment of historically important structures. This can be best exemplified by the restoration of the medieval Langley castle in Northumberland. The unique medieval structure which was constructed in the 14^{th} century is over 600 years old and is currently operating as a luxury hotel. Although the structure has been well retained , various displacements over the centuries have caused cracking on the external masonry. The use of special internal steel rebars for the stabilizing of the structure and the retaining of the exterior of the castle was selected as being the most suitable option, thus the castle was safely and efficiently restored; what more, even normal displacement did not impose any stress on the said structure. Since the underlying surface for the rebars was uneven and in order to retain the external rock face of the castle, some of the groves had to be cut manually in the space between the stone and sandstone blocks joints. The rebars which were then adapted for such groves were inserted and grouted using Helibond. Single and double rebars totaling approximately 400 meters in length were then inserted at various heights. These created lateral harnessing and minimized future cracking. A lime coating was than applied to the walls to retain its originality and to protect the structure.

Another example was a retaining wall built in the 19^{th} century in Hope square in the city of Bristol which was over 100 meters in length and 2.7 meters in height. The wall is located in proximity to Hope Chapel Hill and a narrow pedestrian walk path parallels the wall. The pressure of the earth on one side of the wall had caused it to bulge outwards and created vertical cracks on the wall.

In order to reinforce the wall, mechanical restrainers were installed within the walls . Two special steel rebars were then inserted in the corners of the walls with 450 mm spacing, extending along its length for five meters and embedded in a bed of grout. This caused a reinforcing of the vertical cracks and the creating of structural skeins along the wall, thus reinforcing the wall itself.

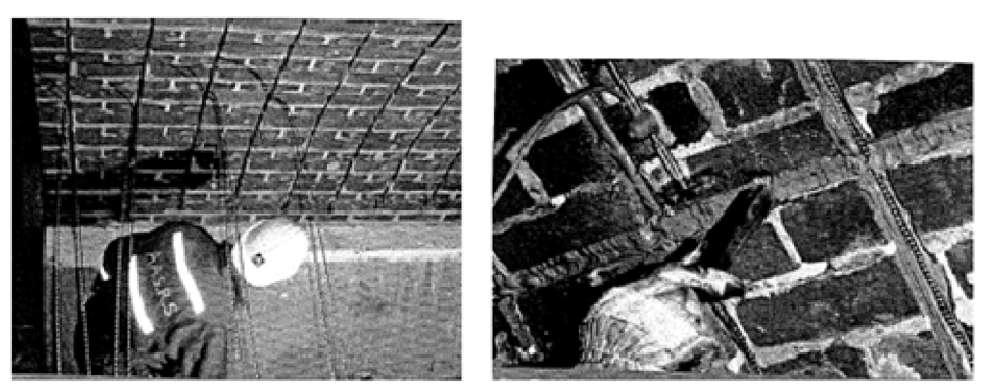


Fig. 30: Sub structural reinforcing for structures (source Dez Ab 2011)

Fig. 31: Sub structural reinforcing of Ghaflankoh railway bridge onTehran – Tabriz route (source Dez Ab 2011)

Fig. 32: Sub structural reinforcing suing special winding steel rebars in stone and brick arches (source Dez Ab 2011)

The benefits of such a system are:

- Economical, reliable and practical
- Increasing the durability of the structure without any adverse increase in density, as compared to conventional rebaring and FRP rebaring
- Behavior of a restored structure
- Permitting the displacement of the structure with no adverse cracking
- Precise computer analysis of the structure
- Designing of an optimization model
- Rapid and harmonious installation based on the geometry and patterning of the structure.
- Sequential and cross sectional installation
- Minimal changes in the original structure.
- Retaining the original exterior of the structure.
- Minimal traffic displacement
- No damage inflicted to embedded structures
- Tested and verified by TRL-England
- Used extensively with positive results over time in historical structures
- Minimal damage imposed upon historical structure

This method can be used for the controlling of localized cracking and also the repairing of deeper fissures in such structures.

3.2.4. Retaining stone walls and intermediate abutments of the arches

The qualitative and quantitative analysis carried out in the study identified the main structural defects in the retaining walls and abutments of the arches and determined the main remedial works as being:

- Controlling the tensile stress imposed upon the wall at the point were it connects to the pedestal
- Controlling shear stress during seismic loading
- Controlling hydraulic erosion
- Optimizing the life span and minimizing environmental erosion.

With due regards to the fact that part of the stone pedestals are within the river and during floods and at normal flow rates water continuously flows around these pedestals, in addition to the stresses imposed by loading and structural elements , the structure must also resist hydraulic erosion.

Based on a needs analysis, and in order to alleviate the problems besetting the pedestals, it is proposed that grouting in addition to crevice filling and surface protection of the pedestals be implemented . The same solution is also proposed for the clay brick structure. Using a mixture of lime and water at 1 or 2 bar pressure, the grouting operations can carried out in both the stone and brick sections albeit taking into consideration the extent of the damage incurred in the said area. The filling in of the space between the bricks and stone should be done with a material which has the same physical and chemical composition of the original filling material. The said material must be water and erosion resistant and not soluble in water, thus a polymer based material with aeration characteristics is proposed.

Tensile stress will not be affected through grouting that much and it is best to utilize the reinforcing techniques mentioned earlier. The grouting pattern will have to defined after experimental grouting and analysis .Eroded or damaged stones can be restored using repair techniques or stabilized.

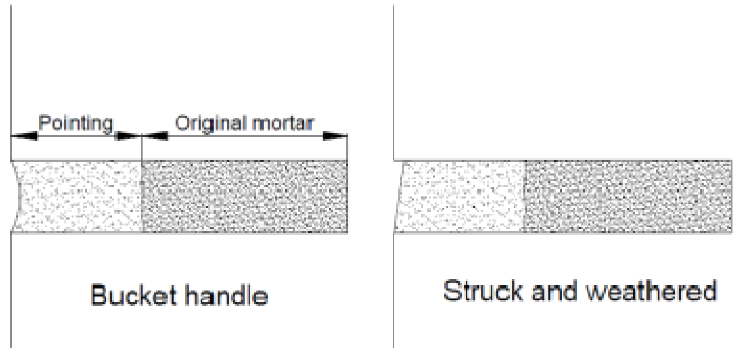


Fig. 33: Filling techniques applied to level the existing and inserted filling (source Dez Ab 2011)

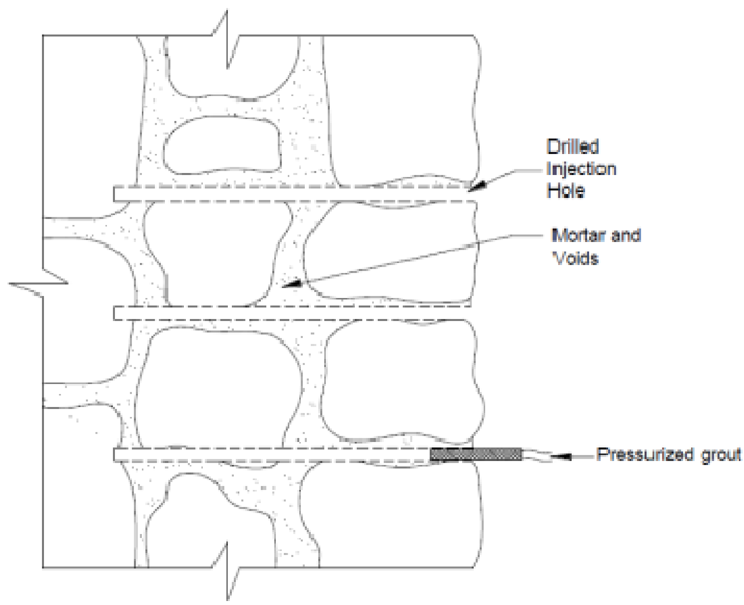


Fig. 34: grouting techniques applied to restore filling (source Dez Ab 2011)

3.2.5. The Foundation of the Bridge

The qualitative and quantitative analysis carried out in the study identified the main structural defects in the foundation of the bridge and determined the main remedial works as being:

- Controlling hydraulic erosion and surface and deep pitting
- Optimizing the life span and minimizing environmental erosion.
- Controlling displacement deformation

The problems affecting the foundation can have an adverse effect on the whole structure itself; hence the rectifying of the problems will ultimately have an optimal effect of the overall stability of the structure. The remaining foundation is a combination of stone mortar and foundation slabs which as per investigation go down to the bedrock of the riverbed itself. The main problem besetting the foundation of the bridge is that of hydraulic erosion which in itself can create many secondary problems. One of the best ways to minimize the problem would be to restore and protect the hydraulic stabilizing structures of the bridge itself especially in the aqueducts. The creating of a concrete slab waterway with a permeable wall upstream and downstream of the bridge can effectively minimize the amount of hydraulic erosion to a great extent. The concrete slab would be in its horizontal section attached to the retaining walls and would control them as per the illustration below. This would also have an optimal effect on the seismic behavior of the bridge itself. The slab must be made of reinforced concrete and be resistant to friction . It is believed that polymer reinforced concrete would a better option than most as it has both of the afore mentioned characteristics.

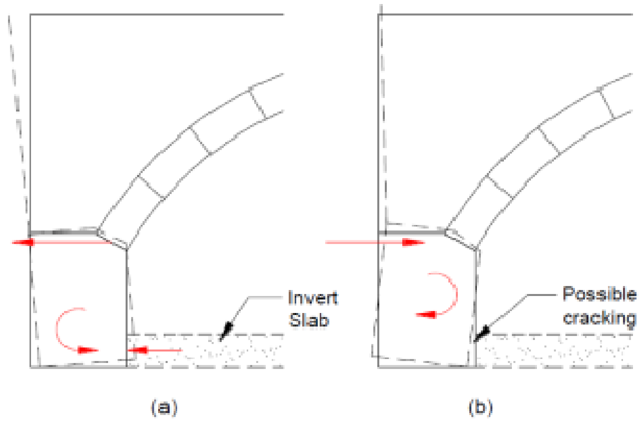


Fig. 35: Operation of concrete slab in minimizing local erosion in the pedestal and modifying the behavior of the structure (source Dezab 2011)

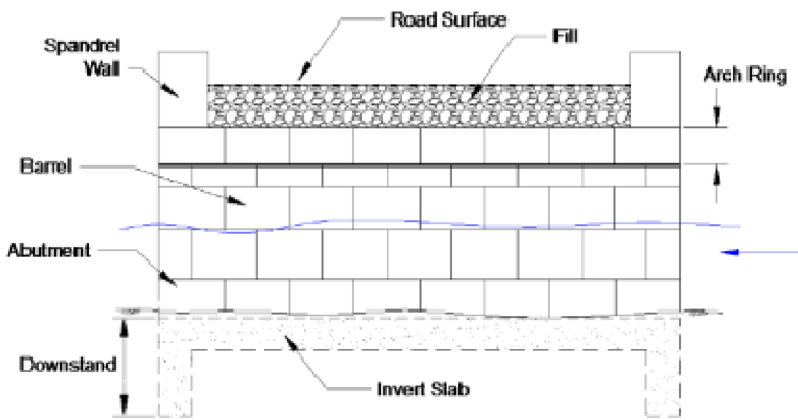


Fig. 36: cross section typical of concrete slab for rehabilitating the foundation with permeable walls upstream and downstream the bridge (source Dezab 2011)

The extending of the concrete slabs on both the inlet and outlet side of the aqueduct should be based on the hydraulic flow pattern so as to minimize turbulent flows and whirlpools; thus in the determining of the final geometry during the implementation phrase this must be taken into account.

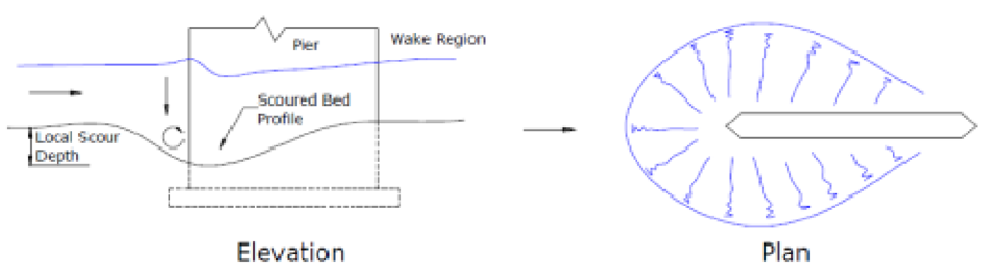


Fig. 37: Prevention of whirlpool and turbulent currents along the concrete slabs

In areas where the erosion has advanced to under the pedestals or in cases where due to the displacement deformation of the structure, remedial modifications are required, in addition to the utilizing of concrete slabs, one must also consider other options which might have an effect on the behavior of the structure especially on its current displacement and the fissures created. This requires and extensive investigation and careful control. The proposed stabilizing strategies proposed in this case are:

- Underwater concrete grouting using an Underpinning method
- Injecting concrete foundation gel using precast concrete via the Preplaced method
- Using micropiles

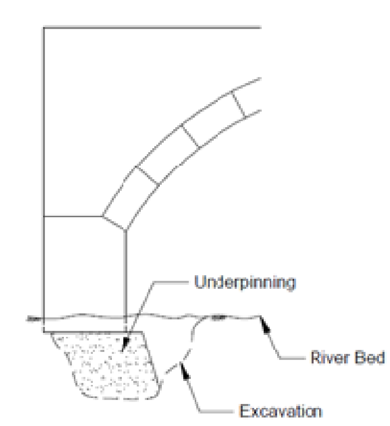


Fig 38: Underwater concrete grouting using an Underpinning method. (Source Dez Ab, 2011)

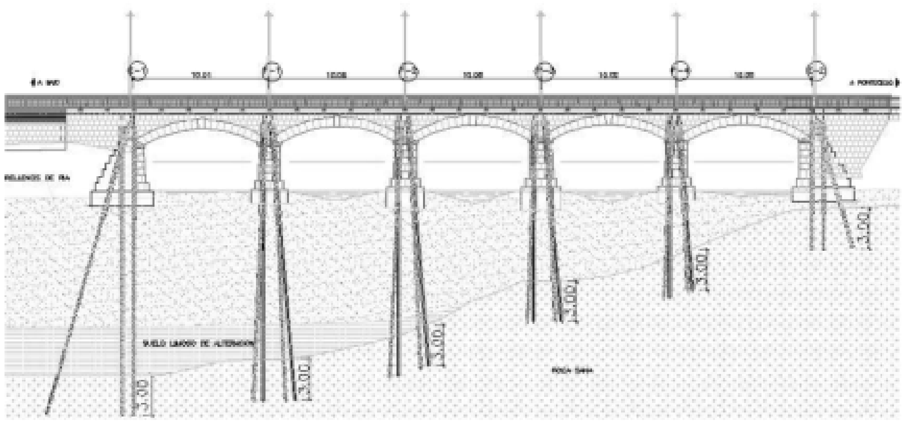


Fig 39: Application of micropiles for reinforcing a foundation. (Source Dez Ab, 2011)

Fig 40: Creating a foundation underwater using an Underpinning method. (Source Dez Ab, 2011)

4.1. Value Engineering and Comparing Reinforcing Methods

In this section the various methods used for reinforcing the old Bridge of Dezful based on the analytical evaluation of the researchers have been presented in the form of a value engineering comparative matrix. The evaluation takes into account issues such as technical; practical; historical; operational; and economical indices.

Each issue has been given a relative value and the sum total determines the methodology which it is believed to be the best solution to the problem. It is of note that the selection of the best option might be skewed due to the practicality of implementation though.

The evaluation has been carried out for the three main sections of the bridge, that is to say the deck; the arches and walls and the foundation. The finalized restoration plan will be selected on the basis of the adding of the safety evaluation index.

Table 2: Comparison of Restoration Methods for Deck

Index	Restoration Method			
	Reinforced steel rebar concrete with protective cover	Polymer Reinforced concrete	Stone or brick paving with grouting Bitumen cover	Asphalt pavement
Technical considerations	10	10	9	6
Historical considerations	8	7	10	7
Provision of Technology	10	10	9	8
Durability	3	10	9	9
Practicality and Costs	9	10	10	10
Speed of Implementation	7	10	6	9
Safety	10	10	10	8
Cost of Materials	8	7	10	9
Total points	65	74	74	66

Table 3: Comparison of Restoration Methods for Arch and Walls

Index	Restoration Method					
	Internal concrete arch and micro pillars	Frame with external steel restraining bands	Sub structure reinforcement using anchoring	Reinforcement using FRP or steel bands with anchoring	External concrete frames or shot concrete or injected corrugated sheeting	Grouting and anchoring in order to tie the structure
Technical considerations	10	9	10	9	10	7
Historical considerations	8	4	9	6	3	9
Provision of Technology	10	9	10	9	10	8
Durability	10	8	10	10	10	9
Practicality and Costs	6	7	8	8	9	8
Speed of Implementation	7	8	9	9	9	8
Safety	7	7	10	10	10	8
Cost of Materials	9	8	7	9	8	8
Total points	67	70	73	71	69	65

The economic evaluation of the various proposed scenarios was based on the evaluation of the total costs for mobilizing, material preparation and transport; in addition to the costs of preparation and cleaning of restoration area and overhead costs which primary preparation might incur.

5. Conclusion and Recommendations:

5.1. Modules of the Final Restoration Solution

Taking into account factors such as implementation, economics; the structure itself the main modules selected for the restoration of the old bridge of Dezful are as follows:

- The restoration of the deck using brick paving in order to make it compatible to the existing structure
- Restoration of the brick arches based on sub structural rebar reinforcement using helibars based on a suitable expansion module
- Restoration of the brick walls using sub structural rebar reinforcement and tensile harnessing under the deck using an anti-corrosive method.

- Restoration of the stone pedestals using localized stitching via self drilling, along with Shell grouting and filling the crevices between the stones.
- Restoration of the foundation using underwater restoration techniques or beneath the eroded areas using Underpinning and localized reinforcement
- Minimizing of Hydraulic erosion using polymer reinforced or rebar reinforced concrete slabs with short cutoffs and with anti-friction characteristics.

5.2. Technical and Operational Specifications and Evaluation of Material

5.2.1. Surface of The Deck and Walls

The best option for the restoration of this section includes a stone structure; along with a specialized mortar having a lime base and shell grouting using a grout such as limepore. The stone used will be of the same type used in the original structure and all historical and architectural considerations will be taken into account.

5.2.1.1. Technical specifications

The grout used in the restoration phase should have the following specifications:

- Specific pressure strength of at least 50 megapixels
- Specific tensile strength of at least 20 megapixels
- Specific cohesive strength of at least 3 megapixels
- The rate of grout to aggregates should be approximately 1 to 5

Table 4: Technical Specifications of the lime based grout

Characteristics	Mean value
Appereance	Powder
Colour	Light grey-hazelnut tones
Application temperature	+2 - +35 °C
pH in water dispersion	11,5 -12,5
Granulometric distribution UNI EN 1015-1 (at 0.09 mm)	100 %
Granulometric distribution UNI EN 1015-1 (at 0.06 mm)	90 %
Fluidity (hollow cylinder method) UNI 8997	70 - 80 cm
Apparent volumetric mass of wet mortar UNI EN 1015-6	1930 ± 50 kg/m³
Workability time of wet mortar UNI EN 1015-9	195 ± 30 minutes
Compressive strength UNI EN 1015-11 (7 days)	> 14 MPa
Compressive strength UNI EN 1015-11 (28 days)	> 18 N/mm²
Flexural strength UNI EN 1015-11 (7 days)	> 2 MPa
Flexural strength UNI EN 1015-11 (28 days)	> 4 MPa

5.2.1.2. Methodology and Operational Considerations

The execution of the deck will occur as follows:

- Balancing and cleansing of the deck and walls
- Flagstone restoration and caulking using a special mortar
- Subsurface shell grouting for the stone and wall structures
- Creating a protective cover for the deck

5.2.1.3. Evaluation of the Quantity of materials Required

The amount and quantity of the material required for the restoration and repairs of the whole structure is as per the table below:

Table 5: Quantity and amount of the material required for the Deck

name	Amount(m^3)	Area (m^2)
Polymer reinforced concrete	300	-
Total Restoration area	-	6800

5.2.2. The Foundation and Substructure

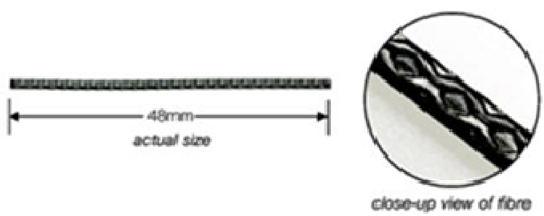
5.2.2.1. Technical Specifications

The concrete and rebars used will have the following specifications:

- The concrete will have a specific pressure strength of 28 days as per a cylindrical model of 30 megapixels and will be compatible with the original mortar of the structure. The type of cement will be a type II cement with a separating sleeve.
- A III rebar will be used for all embedded structures beneath the walls and abutements with a specific concurrent strength of 400 megapixels
- The depth of the concrete over the rebar will be 75 mm
- The concrete slab at the bottom will be made of polymer reinforced concrete with a specific pressure strength of 28 days as per a cylindrical model of 35 megapixels using a cement type II and polyolphin polymers of 4 kg/m^3 at a depth of 20 cm.
- The type of concrete used will be off a self compacting polymer SCC type with durability elements added such as MCI for the alleviating of corrosion and a special facilitator to control the slump and attain the required operational conditions.
- The electrical resistance for the concrete used in the structure should be at least 20 kilohms/cm
- The permeability of the self compacting concrete should be 10-10 m/s in order to meet the durability factor

The concrete used under water should have the following specifications:

- Self compacting
- Resistant to being washed away during pouring
- Having a controlled curing period
- Having minimal hydration and water logging
- Having a strong cohesive strength in the required sectors
- For the covering of the bottom concrete slab , and with due regards to the creating of a strong resistance for friction and erosion due to water flow, polymer reinforced concrete will be used.
- Structural Shogun polymer of a propylene polymer type with a poly oliphin resin can be used to replace rebar sin reinforced concrete such as mesh or shot concrete or even tunnel segments. The characteristics of such polymers are given in the table below.



Characteristic	Material Property
Base resin	Polyolefin
Length	48 mm
Tensile Strength	550 MPa
Surface Texture	Continuously embossed
No. fibres per kg	35,000
Specific Gravity	0.90 – 0.92
Youngs Modulus	6 GPa
Melting Point	150 – 165°C
Ignition Point	Greater than 450°C

Fig41: Characteristics of polymer threads (source Dez Ab 2011)

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