COST ACTION TU1406

QUALITY SPECIFICATIONS FOR ROADWAY BRIDGES, STANDARDIZATION AT A EUROPEAN LEVEL

TU1406 WG4 Final report Appendix A9

Bridge Case study

Girder bridge Joseph Bridge over the Jordan river - Israel

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1. GENERAL DATA ON THE BRIDGE

The inspected bridge is a 36 meter single-span half-through steel truss bridge structure with reinforced concrete slab built in 1956 replacing an old suspension bridge built by the British mandate in 1927. The bridge carries road no. 9779 across the Jordan river between Qiryat Shmona and the Golan heights. Areal map of the bridge location and general pictures are presented below.

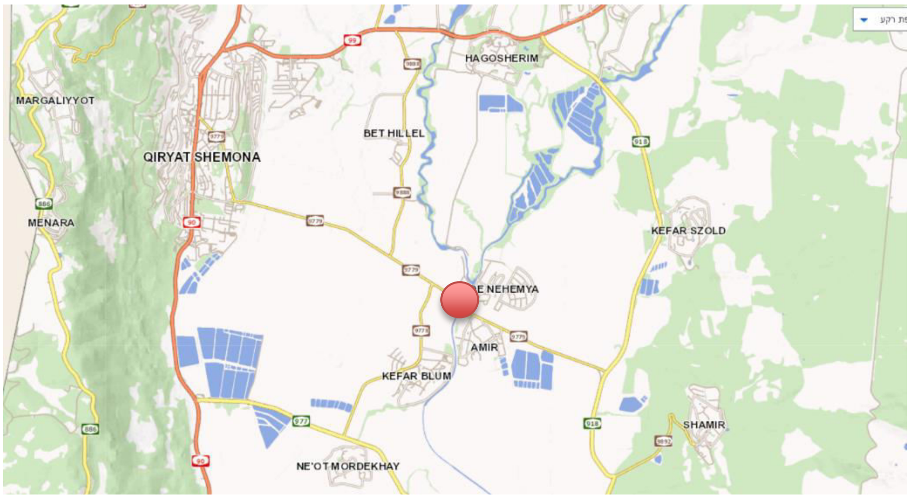


Fig. 1 Map of the bridge area (bridge marked in red dot)

Fig. 2 Side view of the bridge (south side)

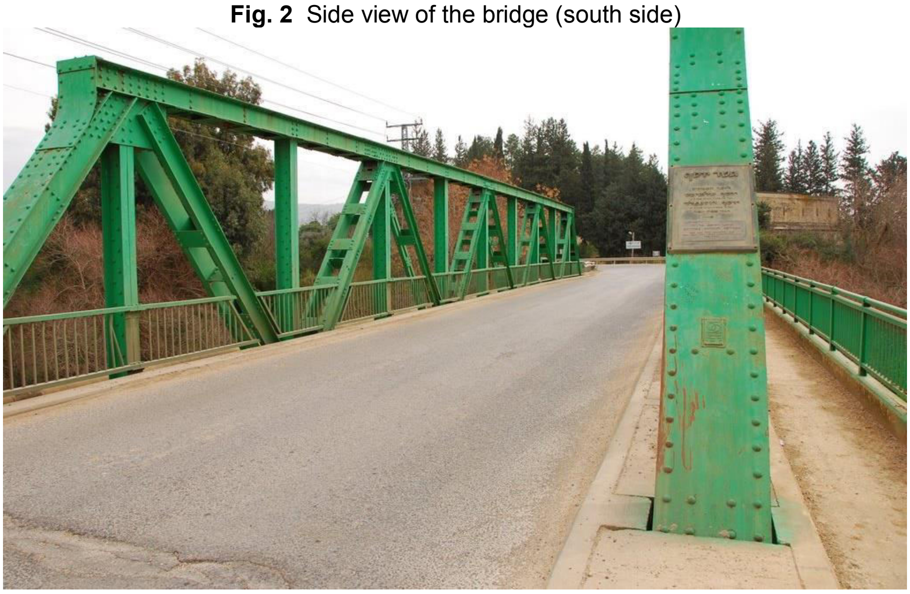


Fig. 3 A view along the road over the bridge (looking east)

Fig. 4 View of the side truss and the Jordan river

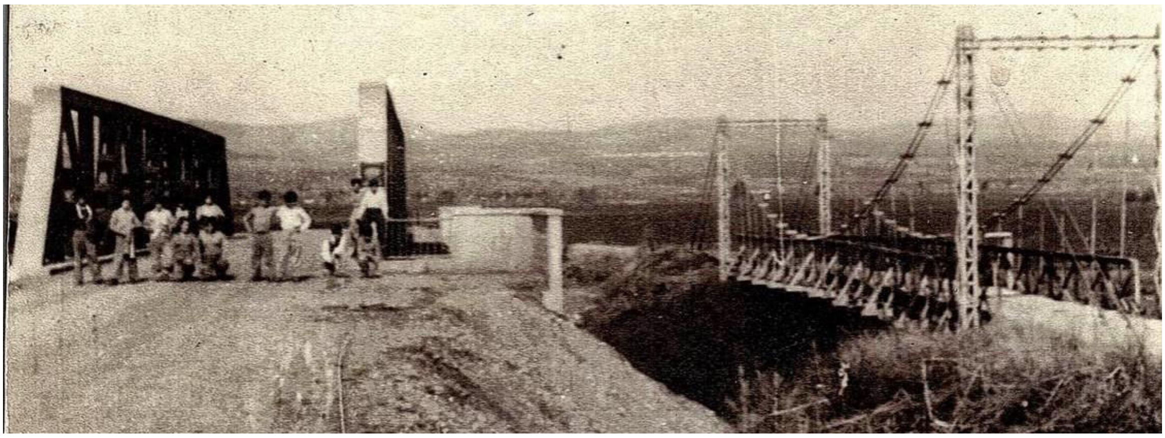


Fig. 5 Historic picture (1956) of the new bridge replacing an old British suspended bridge from 1927.

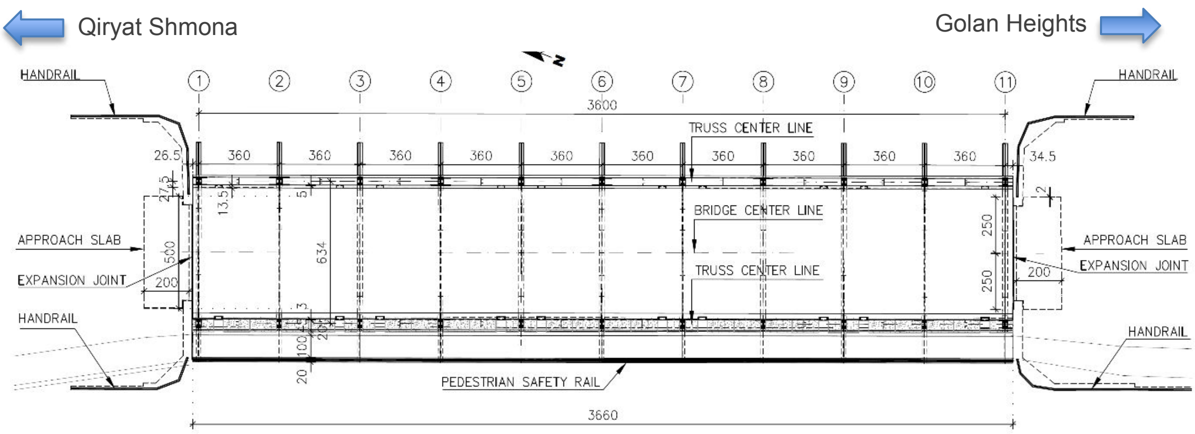


Fig. 6 Plan

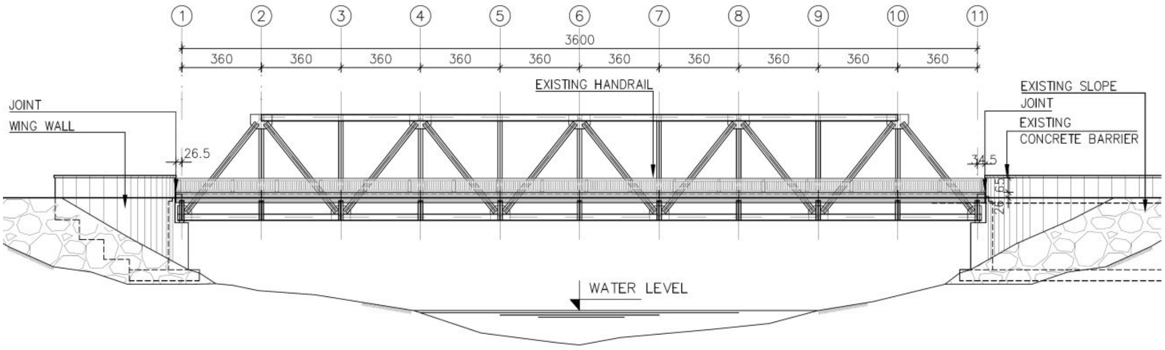


Fig. 7 Elevation of the bridge

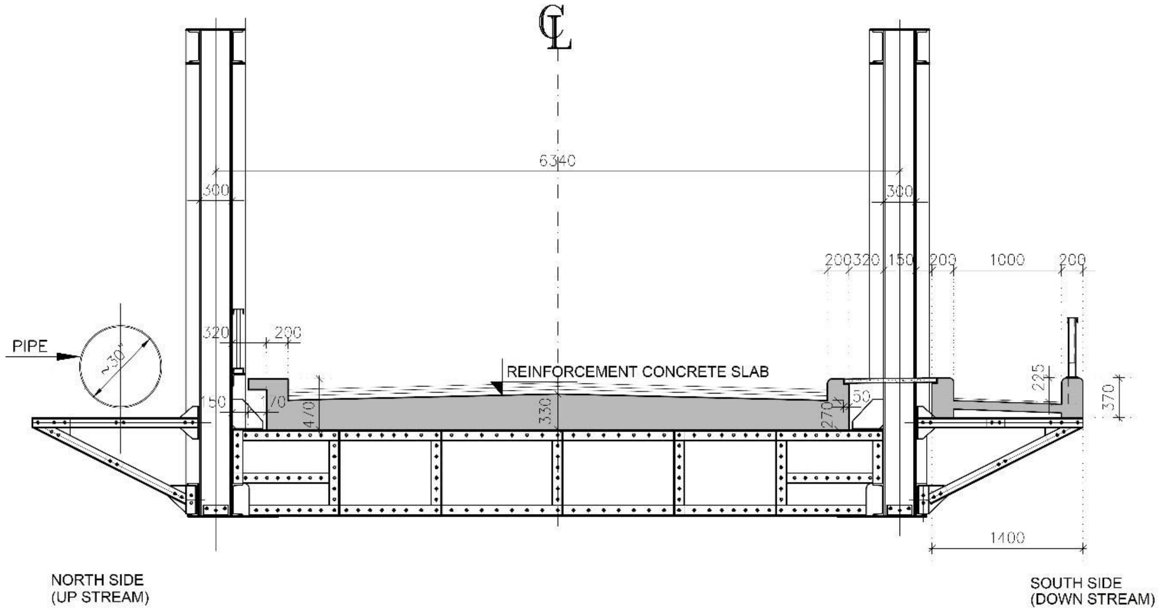


Fig. 8 Cross section of the bridge

1.1. TRAFFIC INFORMATION

The information about the traffic is from the last counting in 2012.
Average annual daily traffic : 6800
Number of heavy cars / 24h : unknown

The bridge is frequently crossed by army vehicles heavily loaded.

1.2. FOUNDATION

Foundations are inaccessible, but the historical existing drawing shows mass reinforced concrete abutments with four rows of hammered piles penetrating into the concrete foundation of the abutment (material of pile is not known but taking into account the year of construction 1956 it can be either steel or wood).

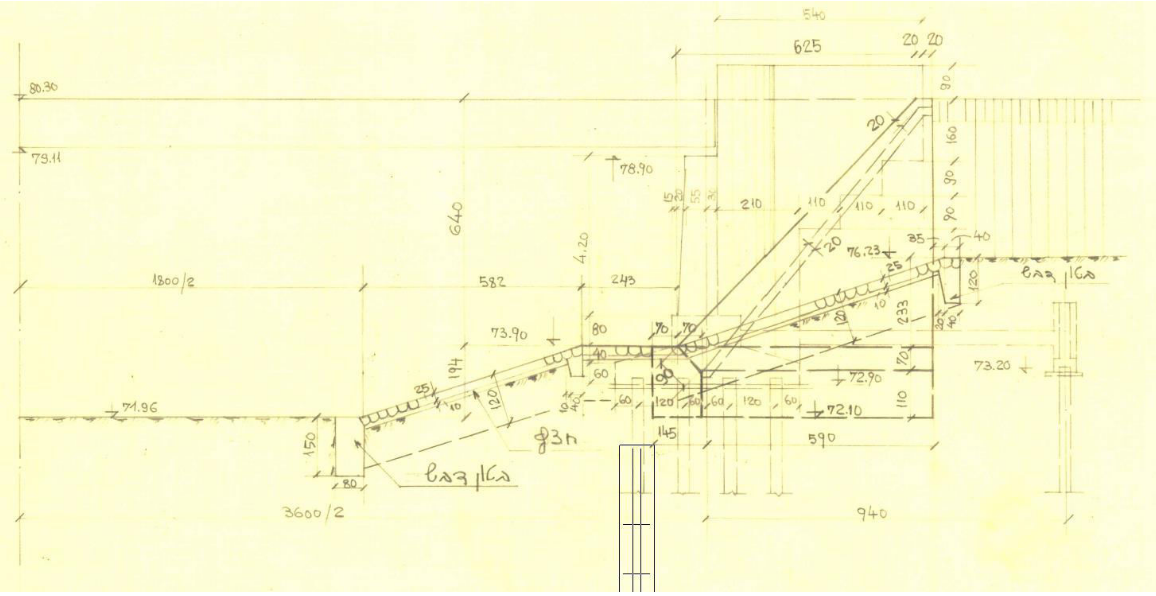


Fig. 9 Cross section of the bridge abutment

1.3. SUBSTRUCTURE

Substructure is formed by two abutments made from reinforced (discovered during investigations) massive concrete with deadman block at the back tied by tension buried girders.

1.4. SUPERSTRUCTURE

The superstructure is composed of 36 meters long half through riveted steel truss divided into ten bays each 3.6-meter long. Two parallel trusses with centerline distance of 6340mm are connected at the bottom cord by eleven rigid transvers cross girders with 810mm depth forming a U shape rigid deck structure. The transverse girders are preventing the longitudinal global buckling of the trusses. Reinforced concrete deck with variable depth of 330mm to 270mm and constant width of 5570mm is connected rigidly onto the transvers girders. The slab is continuous over the transvers girders. At the north side of the bridge a 10" high pressure sewage water pipe is supported by steel cantilever brackets original designed for 30" waterpipe. At the south side of the bridge a pedestrian concrete walkway is supported in a similar way (see Figure 8).

1.5. ACCESSORIES

The deck slab is paved with 60mm asphalt pavement layer. The pedestrian walkway is made of reinforced concrete elements and the pedestrian safety rail is made of steel.
Bearings are pined on the east side and longitudinal movable double rollers on the west side. The original expansion joints are buried under the current asphalt layer thus preventing the functioning of the roller bearings.

Fig. 10a,b,c,d Bridge accessories

1.6. LOAD CAPACITY

Due to the 2011 inspection findings (see clause 3) showing excessive dynamic response to vehicles crossing the bridge, the load capacity of the bridge was immediately reduced to 40 ton as a safety precaution.
This condition caused severe problems as the road is frequently used by heavy military and agricaltural vehicles.

Dynamic load testing and temporary structural monitoring were initiated in order to try and locate the source of the increase vibrations (see clause 4).

The theoretical capacity of each steel element composing the bridge was checked according to the Israeli bridge code IS1227 which is based on the British old code BS5400 for HA, HB & HC loads and found to be satisfactory.

Due to the 2011 inspection findings, a concern raised regarding the integrity of the riveted lower connection of the transverse girders with the main truss bottom chord and truss vertical elements. A FEM calculation model was set and the model was checked for four main cases:

- Case A – monolithic connection between the transverse beams and the truss (as designed).
- Case B – releases in between two transverse girders and the truss (see fig. 11- red circle).
- Case C – releases in between four transverse girders and the truss (see fig. 11- yellow circle).
- Case D – releases between all transverse girders and the truss (see fig. 11- blue circle).

In each case the top chord was checked for:

- Buckling analysis – calculated load factor regarding HA load (in S.L.S.).
- Lateral sway at the top chord of the truss at the midpoint of the bridge according to HC load (1500KN).
- Lateral sway at the top chord of the truss at the midpoint of the bridge according to 600KN load (typical track service load).

Calculation Result:

	Case A	**Case B**	**Case C**	**Case D**
load factor (Buckling analysis)	3.5	3	2.5	0.6
Upper chord lateral sway at mid span according to HC load (1500KN)	8.25 mm	40 mm	48.5 mm	65 mm
Upper chord lateral sway at mid span according to 600KN Truck load	3.4 mm	3.45 mm	4.5 mm	6 mm

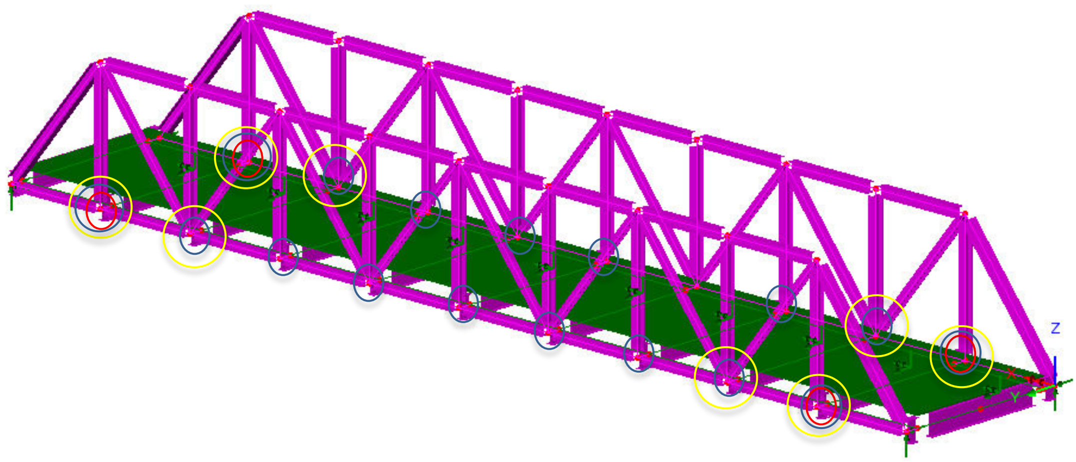


Fig. 11 View of FEM numerical model for checking the bridge truss.

Results of the analysis show that the overall stability of the truss is related directly to the degree of the fixing of the lower cross girder connection with the truss.

1.7. CONDITION RATING OF THE BRIDGE

According to the Israeli bridge condition rating system the status is:

CPI_{av}=72 meaning the structure is in poor to fair condition with moderate to severe damages and possible severe influence on one or more of the bridge or element performance.

CPI_{crit}=55 meaning possible failure of an element with severe defect or damage reducing the load carrying capacity. (taking into account the NDT done later this score will be reduce to 28)

SVIb = 66 The **Seismic vulnerability index** is classified as second grade meaning an action should be taken in the near future for seismic retrofitting of the bridge.

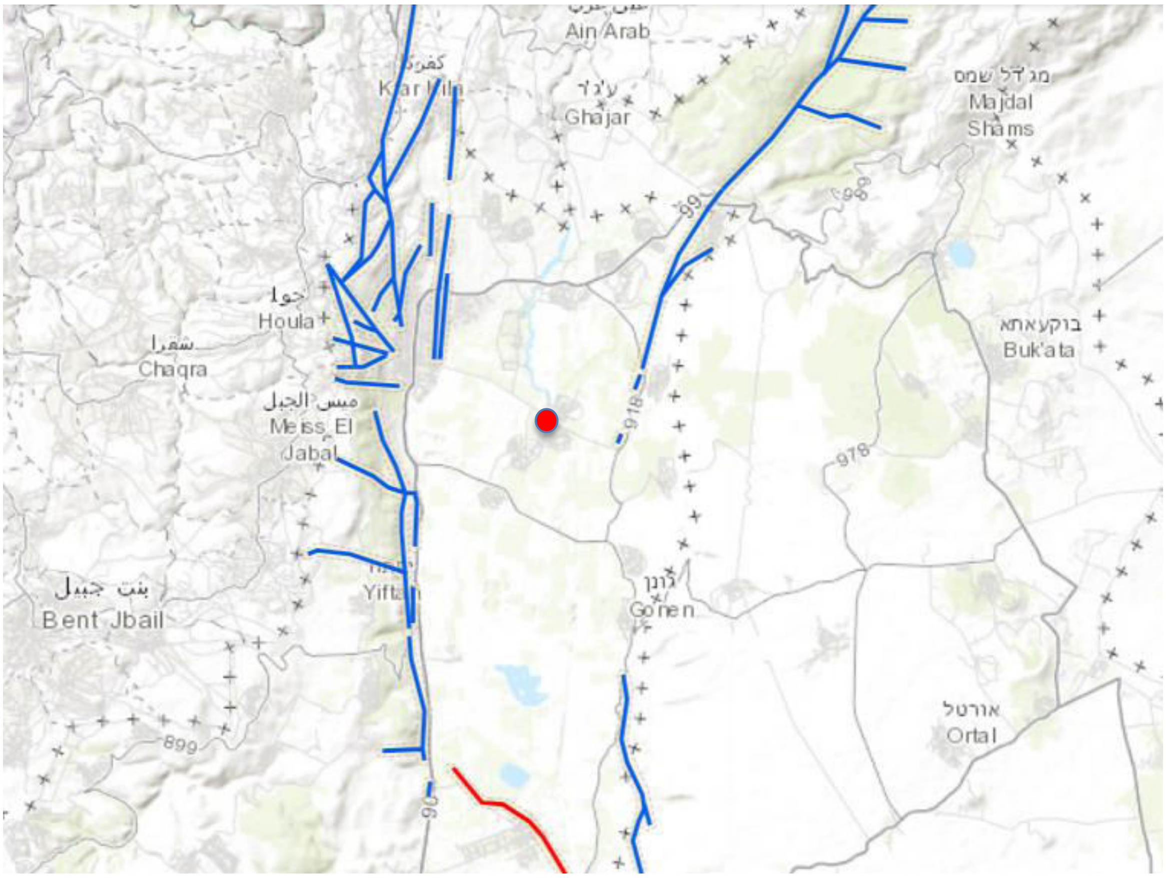


Fig. 12 Syrian African Fault – Vicinity of the bridge

1.8. VULNERABLE ZONES

The vulnerable zones are marked on the following Figures:

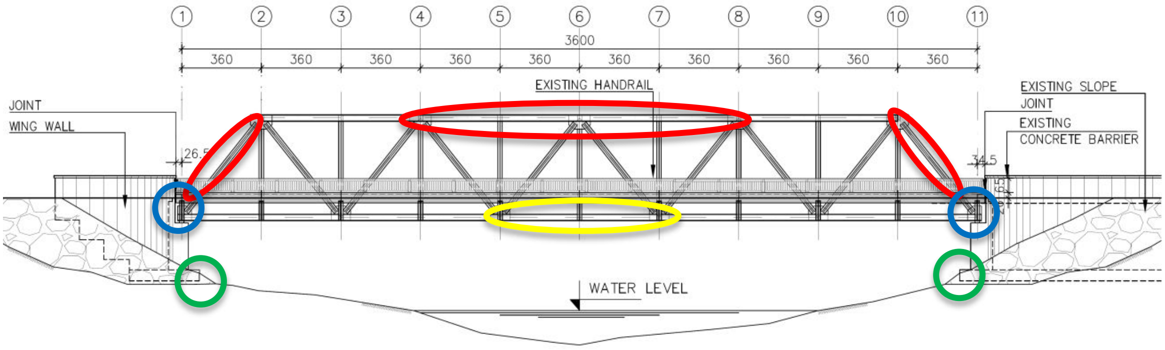


Fig. 13 Vulnerable zones – main truss (Red=high compression zones, **Yellow**=high tension zone, Blue=Bearing area, Area possibly exposed to Scour = Green)

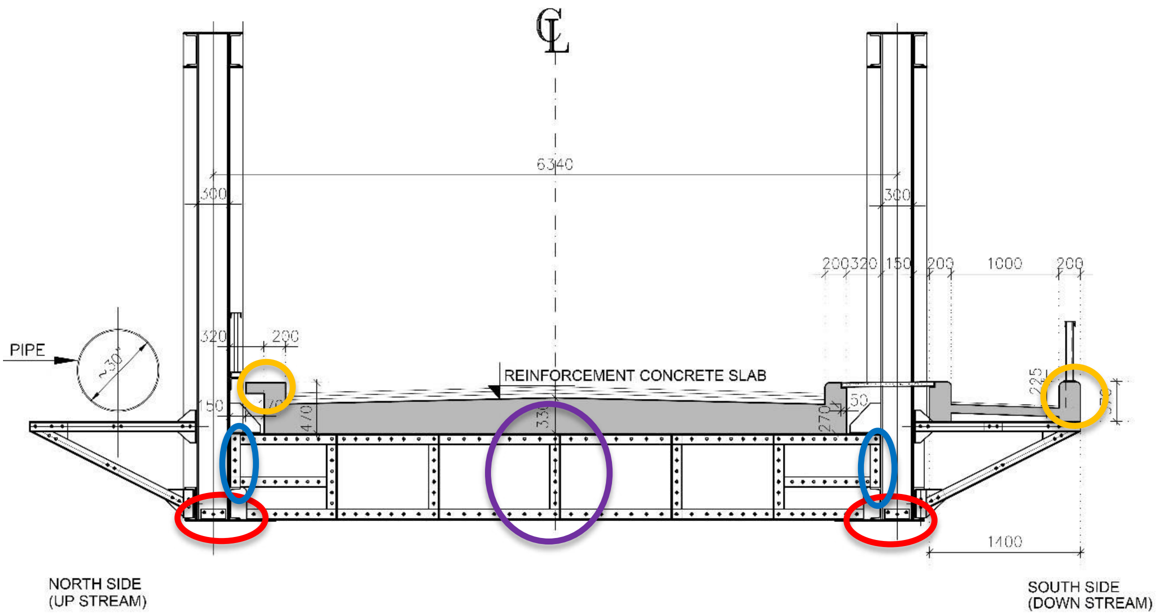


Fig. 14 Vulnerable zones – Cross Girder to deck connection (**Red**= compression zones, Blue=Bearing area, **Orange**= Slab edge, **Purple**= Cross girder sagging)

2. TECHNICAL CONDITION

2.1. COLLECTION OF DEFECTS

The main types of defects discovered on the bridge inspection are:

1. Increased vibration of the bridge during vehicle passing.
2. Mild corrosion of structural steel.
3. Excessive relative movement of rivet head in many locations.
4. Out of plane deformation of steel plates at the bottom girder to truss connections.
5. Concrete deterioration mainly at the deck slab edges and in some locations at the wing walls and abutments.
6. Deterioration of the concrete closing wall behind the roller bearings at abutment A.
7. Accidental damage due to collision of vehicles with main truss vertical and diagonal members.
8. Defects of pavement mainly near the expansion joints.
9. Deck waterproofing not functioning (or missing).
10. Inefficiency of deck drainage.
11. Deterioration of the steel handrailing and collision damages at the north side.
12. Nonfunctioning roller bearings.
13. Limited rotation of the pin bearings due to corrosion damages.
14. Horizontal cracking in layers at Abutment A.

The defects on the main members are presented on the sketches below.

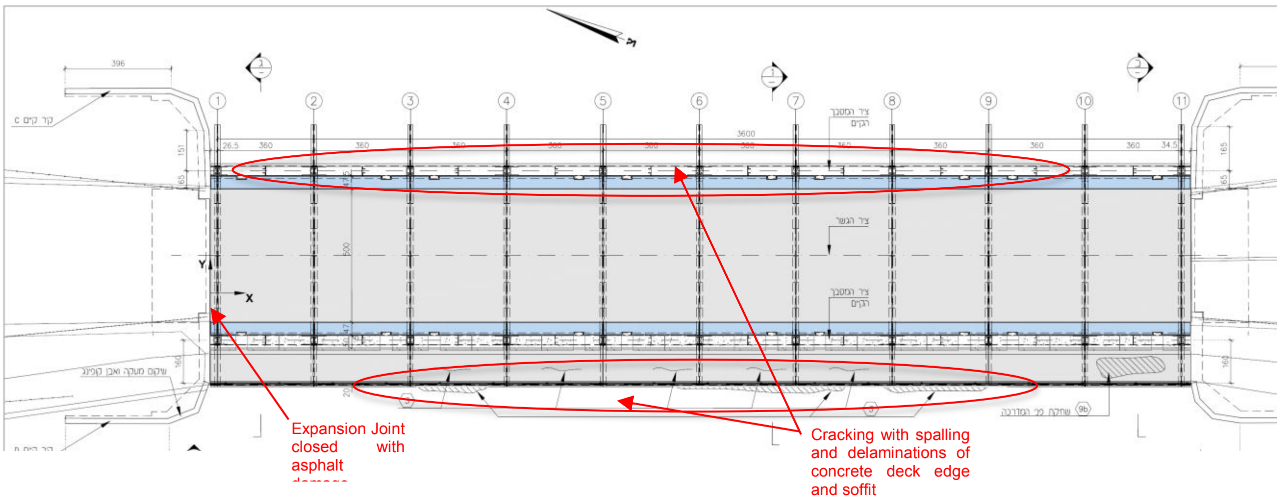


Fig. 15 Plan of the bridge with defects marking

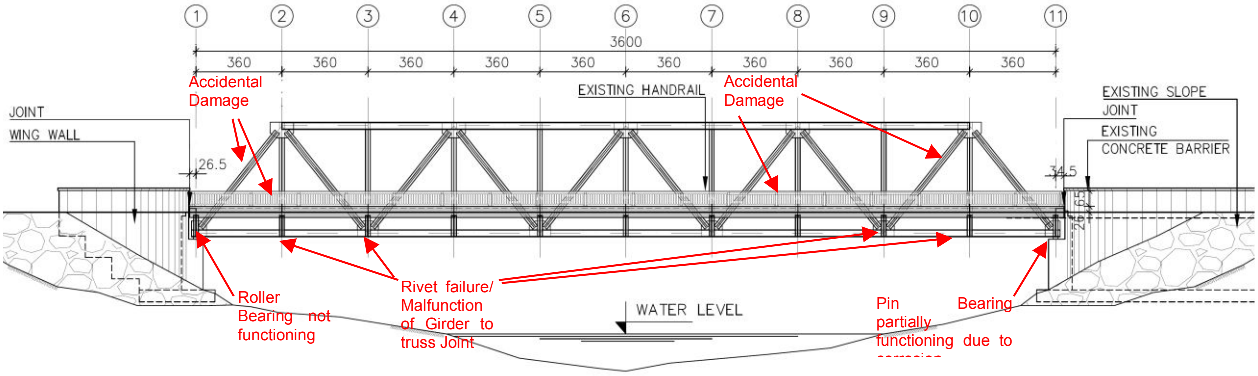


Fig. 16 Schematic elevation of North truss with main defects

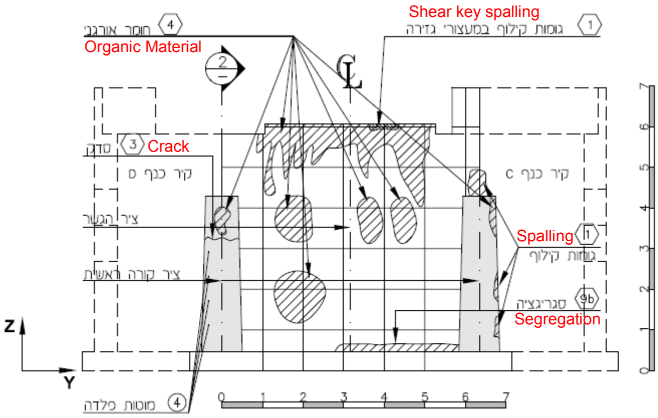


Fig. 17 Elevation of Abutment 1 with defects marking

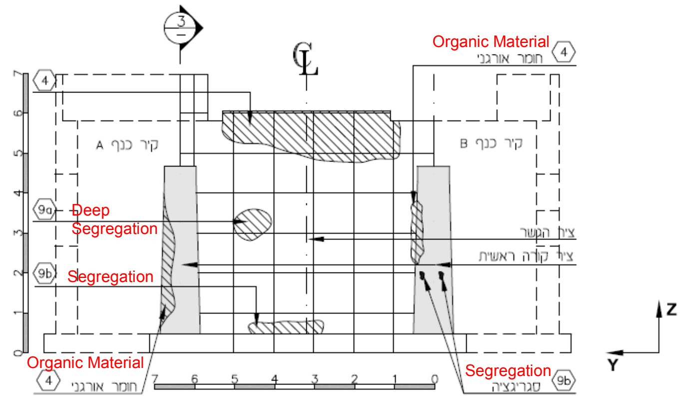


Fig. 18 Elevation of Abutment 11 with defects marking

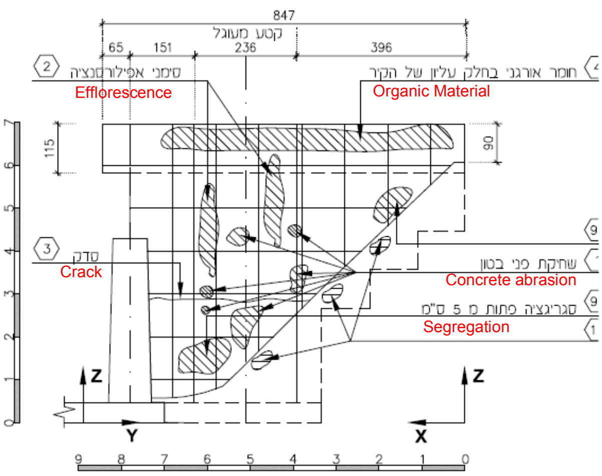


Fig. 19 Elevation of Wingwall 2 with defects marking (similar defects at wing walls 1 & 4)

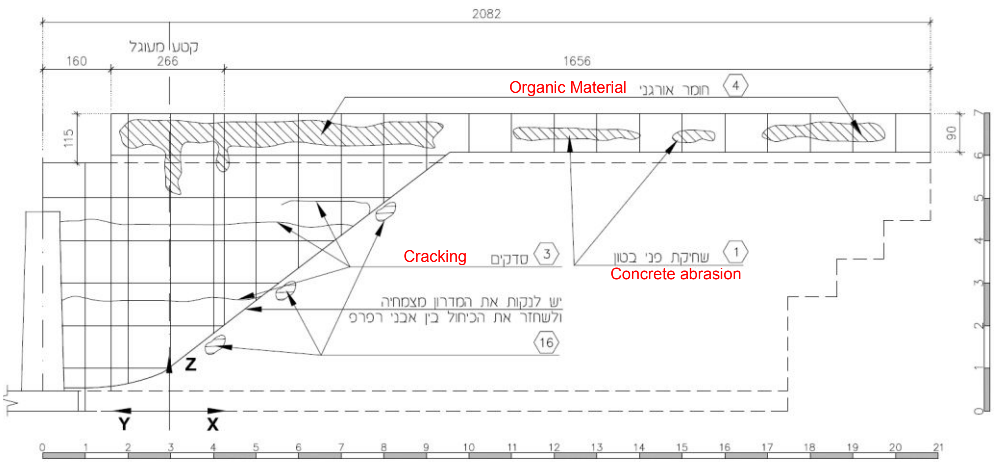


Fig. 20 Elevation of Wingwall 3 with defects marking

2.2. DEFECTS OF THE MAIN STRUCTURAL ELEMENTS

The more important defects are described herein with the relevant picture.

2.2.1. STEEL TRUSS DEFECTS

Fig. 21 Local collision damage to members few locations

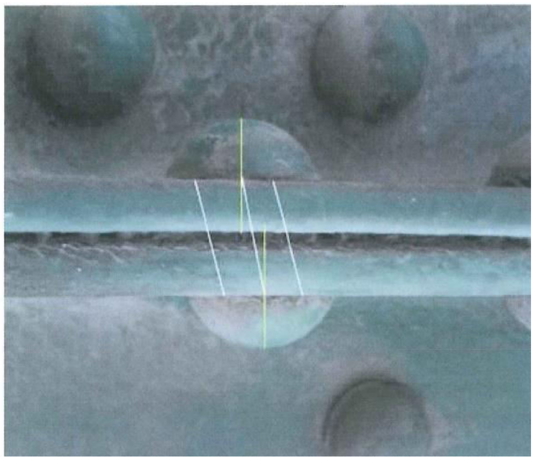


Fig. 22 rivet relative movement

Fig. 23 Sheared rivet due to excessive dynamic loading

Fig. 24 Out of plane deformation at the bottom plates of the truss-girder connection

Fig. 25 Construction welding broken due to fatigue

Fig. 26 Corrosion of truss member (typical condition)
Corrosion between riveted angels and plates

2.2.2.CONCRETE SLAB DEFECTS

Fig. 27 Spalling and delaminations along the deck slab edge (typical along the edges)

Fig. 28 Corrosion at the connection between transverse girder and the deck slab with efflorescence due to water penetrating in between the girder upper

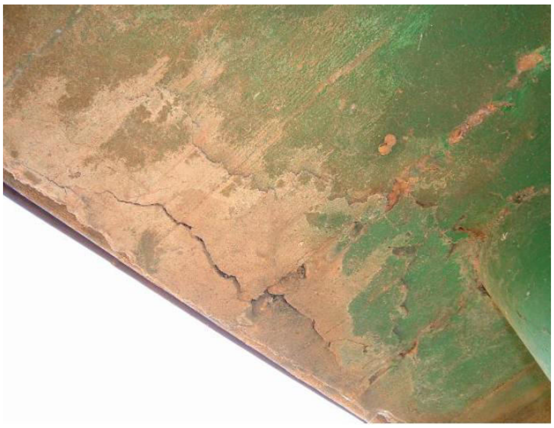


Fig. 29 Corrosion of the reinforcement at slab edge

2.2.3. CONCRETE ABUTMENTS DEFECTS

Fig. 30 concrete spalling at massive abutments

Fig. 31 Concrete surface abrasion at massive abutments

Fig. 32 damage to closing wall near supports at massive abutments

2.2.4. BEARING DEFECTS

Fig. 33 Nonfunctioning roller bearing

Fig. 34 Corrosion damage at fixed bearing

2.2.5. SAFETY BARRIER DEFECTS

Fig. 35 safety barrier collision damage

Fig. 36 Safety barrier collision damage

2.2.6. ASPHALT DEFECTS

Fig. 37 Asphalt defects near and over joints

Fig. 38 Asphalt defects near and over joints

3. POTENTIAL FAILURE MODE OF THE BRIDGE

In accordance with current condition of the bridge following failure modes are considered:

ULS:

- **Truss failure** – Local failure of truss members and riveted section disintegration due to sheared rivets (fatigue).
- **Truss failure** – global bridge failure due to loss of stability of the truss and lateral buckling under heavy live load as a result of transvers girder to truss connection rivet failure (Limiting the sway restrain of the main truss by the transvers girders)
- **Truss failure** – local failure of truss vertical and diagonal members due to accidental load from heavy load transportation vehicle as a result of nonfunctioning safety barrier. This may lead to global truss vertical direction failure (depend on the location of the heat and the member).
  Transverse girder bending/shear failure – Due to excessive dynamic effect of heavy vehicles crossing the bridge.
- **Failure due to Seismic loading** (The bridge is located at high seismic zone) SVIb value is low showing that the bridge needs seismic retrofitting action in short time

SLS:

- **Main Safety Barrier failure** – Due to accidental load from heavy load transportation vehicle
- Pedestrian Safety handrail failure – Due to increased corrosion at the edge and soffit of the pedestrian concrete pathway and loss of anchoring of the handrail vertical members
- **Bearing failure** – Loss of functioning of the roller bearing and rotation of the fixed bearings due to corrosion and accumulation of debris
- **Asphalt pavement failure** – Due to nonfunctioning Joints and drainage.
- **Concrete curb failure** – Possible falling of concrete chunks over the Jordan river where tourists are using boats.

4. NDT TESTING

4.1. RIVET ULTRASONIC TESTING

During the visual inspection of the bridge, the inspectors reported on irregular rivet alignment in many locations over the main truss members and the cross girders. The rivets alignment was checked by 'Ei-Shar' metallurgic laboratory and the suspected rivets were marked. Additional important locations were marked by us based on the static scheme of the bridge and the importance of the connection to the global stability of the bridge.

405 Rivets were tested using ultrasonic equipment 'USM 25 Krautkremer transducers: 4 MHz, 2 MHz 00, 450 Dual & Single probes'. The process included grinding of the rivet head painting prior to the ultrasonic testing.

The indications were classified into three categories: A, B, C. Category A meaning no specific indication result, category B meaning suspected rivet where the indication might be a sign of manufacturing defect or other minor defect and the result does not influence critical elements and Category C were the indication is clearly showing that the rivet is defective.

Over the 405 tested rivets 44 were classified as class B and 9 rivets were classified as class C. All the class C rives and some of the class B rivets were located at the bottom transverse girder to truss connection.

Fig. 39 Results of defect rivet

Fig. 40 Ultrasonic testing of rivets

4.2. MATERIAL TESTING

3 rivets were taken to the metallurgic laboratory for material chemical testing, results will be available soon
.

4.3. DYNAMIC TESTING OF THE BRIDGE

Due to the inspection findings indicating that the vibration of the bridge during heavy vehicles passing is excessive dynamic measurements were conducted by Dr. M. Mogilevsky Laboratory in order to find the actual basic vibration modes of the bridge and compare with the calculated values. Also, the damping coefficient and the influence of a moving truck were calculated.

The test was done using accelerometers and

The fundamental frequency and the fraction of critical damping of the bridge were measured using man weight jumping on the bridge.

A 600 KN full trailer truck was passing on the bridge in 10 to 60 km/hour and 25km/hour with jumping rode located at the expansion joint location. Also the effect of truck emergency breaking on the bridge was checked.

The main results are:

Fundamental frequency = 3.8Hz±0.05 (on vertical direction)

Fraction of critical damping ζ= 0.012÷0.014 (1.2% - 1.4%)

Lateral fundamental frequency of the truss in some cases was 10Hz.

The calculated basic vertical frequency was 3.93Hz

4.4. LOAD TESTING

Bridge load test was performed and the results will be available with the next revision of this report

5. KEY PERFORMANCE INDICATORS AND QC PLAN

Key performance indicators are provided in accordance with best practice knowledge of the team and the experience with bridge inspection in Israel. The indicators are evaluated and failure modes of the bridge are estimated. Two life time cycle approaches are shown to evaluate the life time costs, reliability, availability and safety of considered truss bridge in following 100 years.

First referenced approach considers a lack of any repairs of the bridge except of very basic ones on the pavement. The bridge defects are developed until component or system failure and a comprehensive intervention is performed for the relevant component or system only while others are continuing to deteriorate.

A second Preventative approach consider first major rehabilitation of the bridge and a later periodical set of timely interventions during the life time cycle to prevent further defect development and overall damage to the structure. Seismic retrofitting needed is not included in this scenario and should be analyzed in a different scenario/

5.1. CURRENT STATE EVALUATION

In accordance with current state of the described structure following KPIs are considered:

Structure type	Group	Component	Material	Design & Construction	Failure mode	Location/ Position	Damage /Observation	Damage process	KPI	Performance Indicator component level		Performance value R	Performance value S	Estimated failure time [years]
TB	Structural elements	Main Trusses	Steel	1954	Truss Bending failure mode	Upper chord compression zone	Corroded plates	Corrosion	Reliability (Structure safety)	2.3	4.1	4.1	2.1	**40**
							Corroded rivet	Corrosion		2.3				**40**
						Lower chord tension zone	Corroded plates	Corrosion		2.3				**40**
							Corroded rivet	Corrosion		2.3				**40**
					Truss Shear failure mode	Diagonals	Corroded plates	Corrosion		2.3				**40**
							Corroded rivet	Corrosion		2.3				**40**
							Accidental damage	Impact		2.0				**20(?)**
					Global buckling of truss upper chord	Connection of truss verticals with deck cross girder	sheared rivet	Fatigue		4.1				**15**
							Out of plane movement of lower connection plate	Fatigue		4.1				**20**
		Cross girders	Steel	1954	Bending	High sagging area	Shear connection with deck corroded	Corrosion		2.1	4.1			**30**
					web plate buckling	Bearing area over main truss	Rivets are partially sheared	Fatigue		4.1				**20**
					Bending	Along the girder	Corroded rivet	Corrosion		2.1				**40**
		Deck slab	Reinforced concrete	1954	Bending	HMS/bottom	delamination	Corrosion	Reliability	2.1	**2.1**			**30**
				1954	Falling chunks	bottom	Spalling	Corrosion	Safety (Life and limb)	2.1	**2.1**			**30**
				1954	Bending	HMH	Efflorescence	Leaching	(Symptom)	(2.1)				
		Bearings	Steel	1954	Bearing Failure	Abutment 1 (west)	Corrosion	Corrosion	Reliability	2.0	**4.0**			**40**
		Bearings	Steel	1954	Bearing Failure	Abutment 1 (west)	Bearing restrained no movement due to	Corrosion	Reliability	4.0				**20**

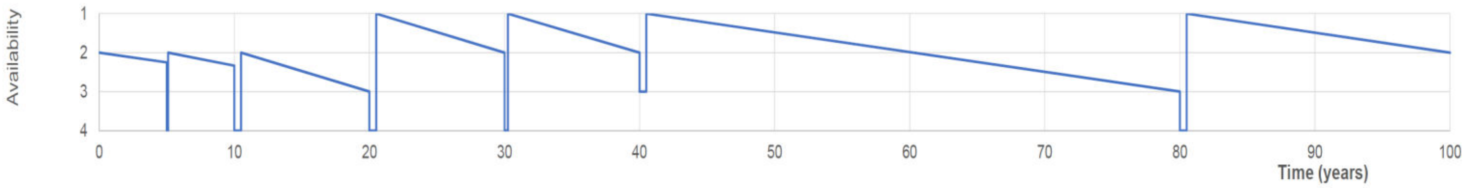
							corrosion and debris							
		Bearings	Steel	1954	Bearing Failure	Abutment 11 (east)	Loss of rotation ability due to Corrosion	Corrosion	Reliability	3.0				**20**
		Abutment	Reinforced concrete	1954		Abutment 1 (west)	Spalling and delamination at closing wall	Joint leaking	Reliability	3.0	**3.0**			**20**
		Abutment	Reinforced concrete	1954	Bearing Failure	Abutment 1 (west)	closing wall with horizontal crack	Closing of joint	Reliability	3.0				**20**
		Wing wall	Reinforced concrete	1954		Wing wall	Horizontal cracking		Reliability	2.1	**3.3**			**-**
		Wing wall	Reinforced concrete	1954		Wing wall	Spalling	Corrosion	Reliability	3.3				**-**
		Wing wall	Reinforced concrete	1954		Wing wall	Surface abrasion	Abrasion	(Symptom)	3.3	**-**			
		Expansion Joint	steel	1954	Closing	EJ 1 (west)	Closing of EJ	Deck movement	Reliability	3.0	**3.0**			
		Pedestrian Deck slab	Reinforced concrete	1954	HMH	Over transvers supporting truss	Transvers cracks	Not active	Reliability	2.3	**2.3**			**20**
		Pedestrian Deck slab	Reinforced concrete	1954	Falling chunks	South Edge	Spalling	Corrosion	Safety (Life and limb)	3.3	**3.3**			**20**
	Equipment	Safety barrier	Steel	1954	Falling of the deck	Safety barrier	Broken, missing parts	Impact	Safety (Life and limb)	3.0	3.0			**10 (?)**
		Pedestrian Handrail	Steel	1954	Falling of the deck	Handrail anchoring	Corrosion of structural steel	Corrosion	Safety (Life and limb)	2.7	2.7	**-**	**3.3**	**30**
		Curb	Reinforced concrete	1954	Falling chunks	Curb side	Spalling, delaminations	Corrosion	Safety (Life and limb)	3.3	3.3			**20**
		Pavement	Asphalt	Estimated 2005	Sudden disturbance to driver	Expansion joints overlay	Open transvers cracks	Joint reflection cracking	Safety (Life and limb)	3.3	3.3			**5**

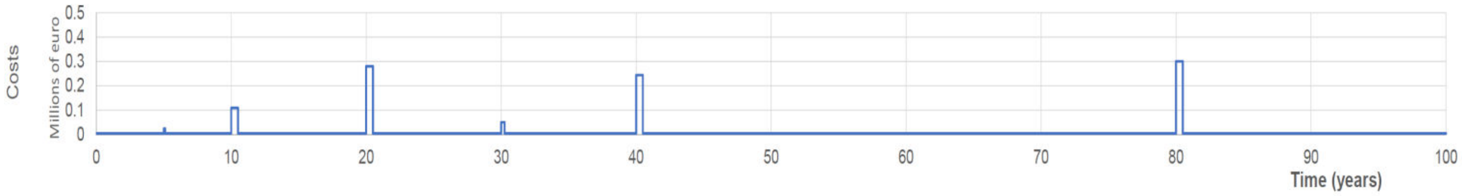
The estimated failure time is assumed according to the team experience with steel and concrete structures in Israel and estimated progress of the defects. Further work should be done regarding this part.

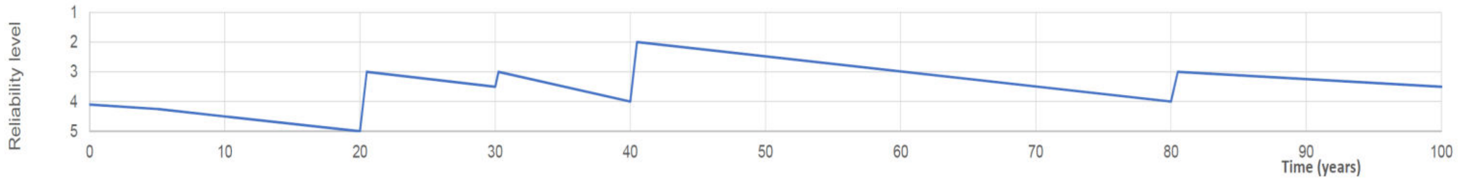
5.2. REFERENCED APPROACH

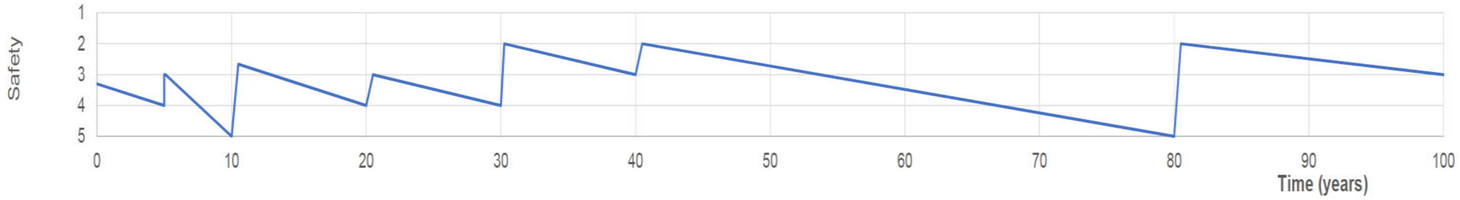
The reference approach is lacking of any major repairs of the bridge component and accessories except for periodical pavement repairs. This approach leads to the defects development up to the bridge failure. In accordance with the previous sections. The existing structure defects development and estimated failure times are assumed as follows:

- Pavement failure in five years due to crack development over the expansion joints and creation of potholes which will reduce the safety of the driver and also might increase the probability for accidental impact load hitting the main truss members. (as noted the pavement layer shall be repaired in the reference case).
- Steel safety barrier will collapse in 10 years due to possible accidental damage.
- Failure of the connections of the truss vertical members with the cross girder is expected in 15-20 years due to the influence of the fatigue on the rivets and it is expected (based on the actual defects found already) that this phenomenon will progress in time. This situation will cause reduction of the factor of safety against upper compressed chord global buckling as calculated in the FEM (see clause 1.6).
- The influence of corrosion development on the different components of the bridge is predicted to reach in 30 to 40 years' time based on the site climate and the current corrosion state.
- Spalling at the bottom of the slab edges and at the curbs is predicted to develop into unsafe condition to the users of the boat service passing below the bridge in 15-20 years.
- The anchoring of the pedestrian handrail is deteriorating due to corrosion and expected to fail in 30-year time.









5.3. PREVENTATIVE APPROACH

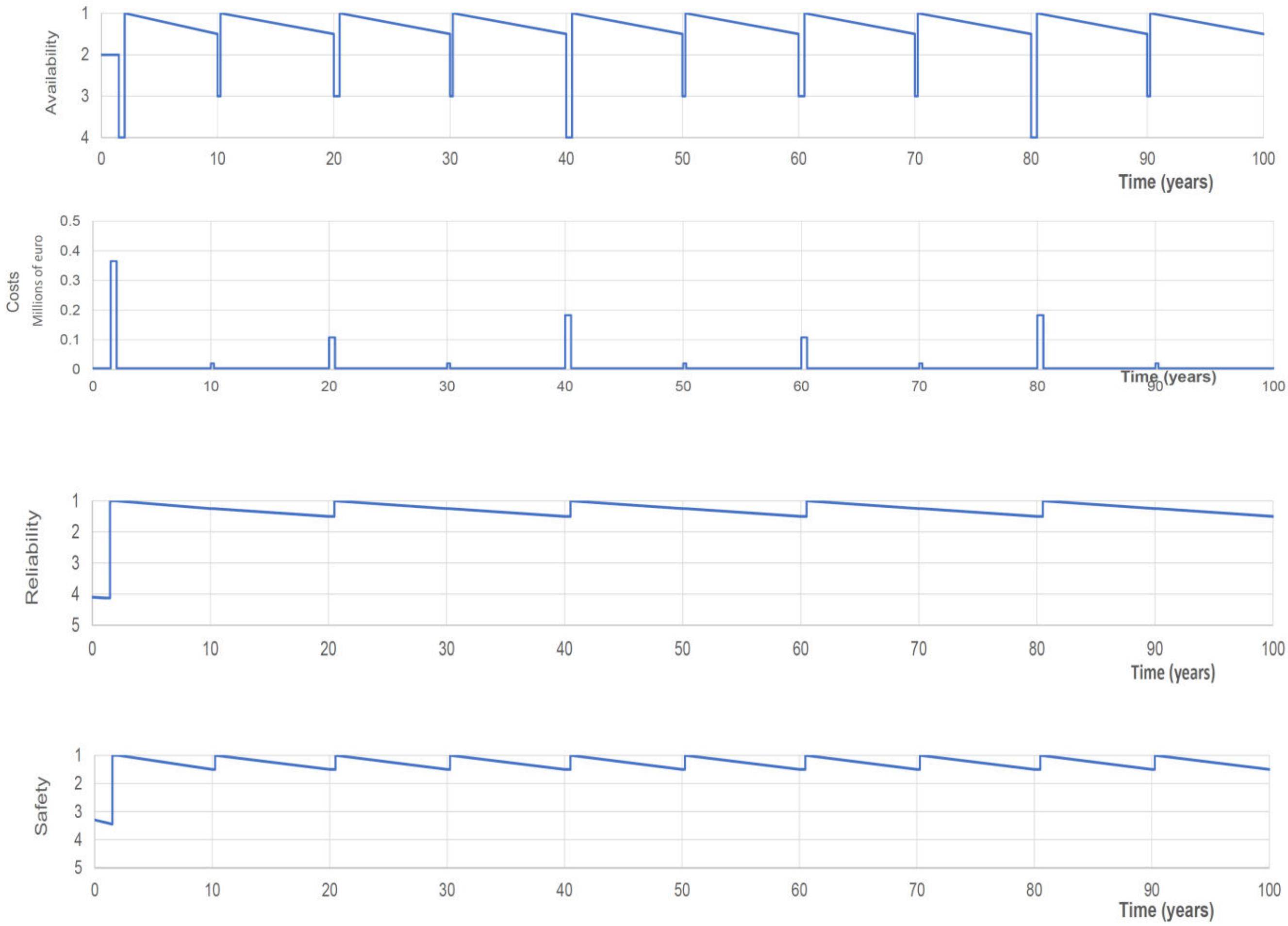
The preventive maintenance approach shown herein is one of few possible life cycle approaches. The presented approach takes into account that the bridge is going to be completely rehabilitated bringing its reliability index to the maximum possible target which is 'as new'. The intervention will take place in the next two years after the design will be made. Following this massive intervention, a preventive intervention regime is established with 10 years. 20 years and 40 years periodical intervention defined with the related costs. The costs are calculated based on actual process of the region bridge maintenance contractor contract. The life time cycle is considered as follows:

The immediate bridge rehabilitation includes: Complete concrete elements repair, Concrete curb replacement, joints connection repair including about 400 rivets replacement and plate replacement, overall bridge painting, New expansion joints, bearing rehabilitation, replacing safety barrier with new one including end blocks, rehabilitation of the pedestrian handrails, pedestrian deck overlay, new waterproofing and asphalt overlay. The cost includes the temporary traffic arrangement needed.

The 10 years intervention includes: Upper layer asphalt paving and safety barrier rehabilitation (based on the actual accidental incidents that will happen during that time. The cost includes the temporary traffic arrangement needed.

The 20 years intervention includes: 10 years intervention + overall concrete surface treatments, overall painting system renewal, In depth NDT of the truss connections (before repainting), EJ rehab./replace, The cost includes the temporary traffic arrangement needed.

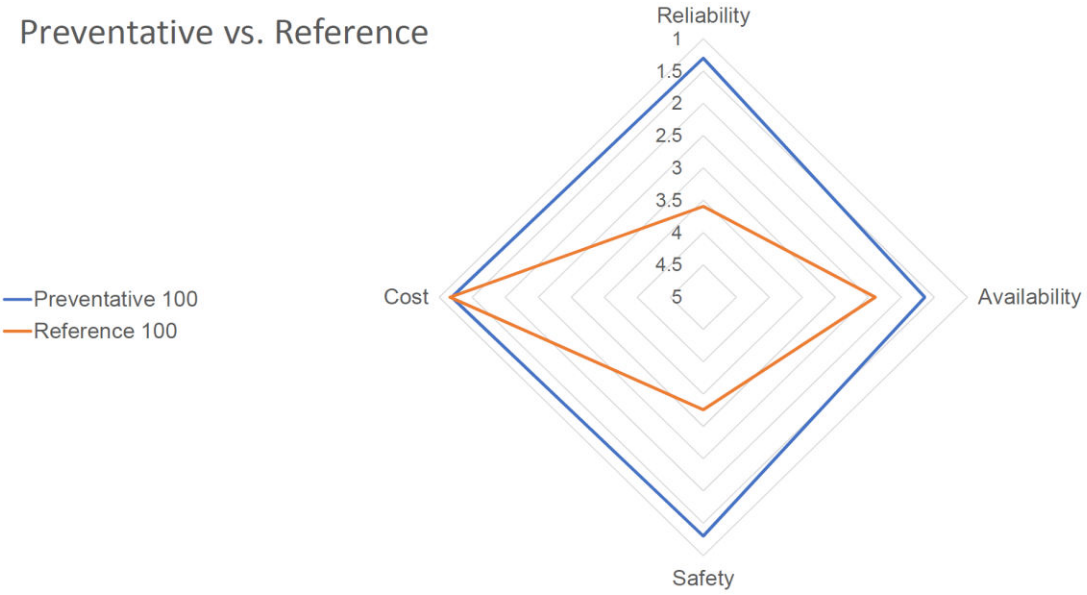
The 40 years intervention includes: 20 years intervention + rivet replacement (estimated 500 units), Bearings rehabilitation/replacement, renewal of deck waterproofing system. The cost includes the temporary traffic arrangement needed.



5.4. COMPARISON OF THE APPROACHES

A comparison of the two considered approaches is shown in following “spider” diagram:

According to the analysis the preventative approach is clearly more appropriate for this truss bridge – The cost is little more but all other indicators shows more favorable results for all aspects. The reliability and safety are kept in higher levels all over the period.



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