**Innovative Design Approach of Using Biaxial Double Twist Steel Wire Mesh Asphalt Reinforcement for Safawi-Iraqi Border Road Rehabilitation Project**

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**ABSTRACT**

Safawi-Iraqi border is an arterial roadway within the eastern part of Jordan, which connects the country with Iraqi borders. This road comprises of flexible pavement with two lane roadway and asphalt paved shoulders of varying widths, constructed in the early 1990’s. No maintenance or repair records were available for the last 30 years. Recently, the contract of rehabilitation of this road project was awarded to a contractor. The original design required the milling of top 14cm thickness of the bituminous layers, followed by placement of 12cm thick new bituminous layers. Since the stretches identified with severe distress and applicable with above proposed solution is as lengthier as 20km, the rehabilitation works will be expensive and time consuming. Thanks to the use of the asphalt reinforcement, an alternate cost-effective solution was provided. Based on the pavement thickness, modulus values and traffic loading details, it was possible to design a maintenance solution with a thinner overlay (only 7cm). This paper present in detail the design approach and the construction advantages to evaluate the benefit of the asphalt interlayer system in the Safawi-Iraqi border road rehabilitation project.

**INTRODUCTION**

The Safawi-Iraqi border roadway has been constructed in the early 1990’s as part of Azraq Iraqi borders road project. It is an arterial roadway within the eastern part of Jordan, which connects the country with Iraqi borders. During the first two decades of its life, this road has been used intensely; serving goods trucks between Jordan and Iraq and tanks transporting fuel from Iraq to Jordan, after then, the mutual traffic decreased significantly due to political implications. In addition to the climbing lanes at upgrade sectors, the roadway mainly comprises of flexible pavement with two lane roadway and asphalt paved shoulders of varying widths.

As per the ‘Pavement Evaluation Report’ of the project (EAS, 2016), there are no records of maintenance or repair records on this roadway for the last 30 years. The roadway vicinity belongs to the desert arid zone, which is generally characterized by its hot climate and relatively long hot season of high temperatures during day time. In addition, there is a relatively high temperature gradient between day/night times where temperature drop in night may approach the freezing point in winter.

The details of the stretch of the roadway presented in this paper is under a maintenance contract awarded in year 2016 by the employer. According to the stationing of the said
maintenance project, the segment understudy falls between station 126+000 and station 165+800, starting from Iraqi border towards Safawi city (see figure 1 for the aerial view of road route).

**EXISTING ROAD CONDITIONS**

The ‘Pavement Evaluation Study’ (EAS, 2016) revealed that the roadway suffers from different types of distresses and failures, mainly caused by cracking associated with spalling and depressions at some areas. Pavement of the worst condition suffered from block and or alligator cracking associated with pavement depressions at some areas of cracking of high severity levels. In addition, linear (longitudinal and transverse) cracking was also noticed on the remaining roadway segments.

**REHABILITATION SOLUTIONS**

Based on the prevailing pavement conditions, prevailing distress and the probable mechanism of the governing distresses, the ‘Pavement evaluation report’ (EAS, 2016) recommended the partial milling and reconstitution of the asphalt layers, as the most effective approach of rehabilitation of the roadway. To be specific, the employer required the contractor to mill the top 14 cm thick bituminous layers and reconstitute by laying 12 cm thick new bituminous layers. However, the
stretches identified with severe distress and applicable with above proposed solution is as lengthier as 20 km, the rehabilitation works were foreseen to be expensive and time consuming.

Thanks to the use of the asphalt reinforcement; an alternate cost-effective solution was provided. Based on the pavement thickness, modulus values and traffic loading details, it was possible to design a maintenance solution with a thinner overlay (only 7 cm). Following a simplified design method developed by Nottingham University, the design solution forecasts a life of 25 years for the pavement without compromising on the performance and traffic load requirements.

FUNDAMENTALS OF REFLECTIVE CRACKING

HMA (Hot Mix Asphalt) overlays are applied to an existing pavement (old or new) when the structural or functional conditions of the pavement have reached an unacceptable level of deterioration. Most of the overlays are designed to reflect the increase in pavement resistance to fatigue and rutting distresses. Pavements that are structurally sound after the milling of cracked old wearing course and placement of new overlay are generally designed against rutting and fatigue distresses but may show a cracking pattern similar to that which existed in the underlying pavement after a short time. This pattern is known as “reflective cracking”. Reflection cracks are caused by existing discontinuities (cracks or joints) in underlying layers, which propagate through a HMA overlay from continuous movement at the crack prompted by thermal expansion and traffic loadings. If the new overlay is bonded to the distressed layer, cracks in the existing pavement almost always propagate to the surface within a short period of time.

Two distinct phases are considered in the cracking process of new pavement systems (neglecting the ultimate failure stage, in which the crack growth rate increases rapidly as global instability is approached):

1 – Initiation phase
2 – Propagation phase

The crack initiation phase is composed of two stages of micro cracking and the formation of macro cracks. It is further defined by the number of load repetitions required to form a damaged zone with a visible small crack in the overlay. The original damage may occur at the bottom of the HMA layer and grow upwards, or directly shows at the surface from the stress concentration around the tire treads. The number of cycles of a specific load a pavement can withstand before it cracks may be related to the critical strain using a fatigue law:

\[ N = C \varepsilon^a \]

where:
N = number of cycles before crack initiation;
\( \varepsilon \) = critical strain;
C = constant of the fatigue line;
a = slope of the fatigue curve.

When the reflection of cracks is considered, the number of load repetitions before crack initiation may be much shorter than with regular distresses (such as fatigue cracking) since the crack is already well established in the existing pavement.

The crack propagation phase represents the stage in which the crack propagates to the surface through the entire thickness of the HMA overlay. A description of the crack propagation phase in flexible pavements can be based on the empirical power law:
\[
\frac{dc}{dN} = A (\Delta K)^n
\]
where:
- \(c\) = crack length;
- \(N\) = number of loading cycles;
- \(A, n\) = fracture parameters of the material;
- \(\Delta K\) = stress intensity factor amplitude.

**ASPHALT REINFORCEMENT WITH DOUBLE TWIST STEEL WIRE MESH**

Bi-axial double twist steel wire mesh has been used successfully for solving problems in pavements worldwide over the past few years. Bi-axial double twist steel wire mesh was originally conceived as an interface layer, which could reduce crack reflection. Further research identified that the unique geometry and high tensile strength at low strain properties of the steel mesh introduces a fundamental tensile stress bearing benefit to the stiffer asphalt layers. A significant increase in service life can be expected for overlays over reflected or fatigue cracks and in overlays over roads that experience heavy traffic or poor foundation conditions.

The current bi-axial double twist steel wire mesh application portfolio includes solutions for:
- Reinforced overlays over jointed rigid pavements;
- Reinforced overlays over semi-rigid pavements;
- Reinforced pavements experiencing heavy traffic, poor foundation conditions, or surface rutting problems;
- Road Widening (for longitudinal transition cracks).

**BACKGROUND TO PAVEMENT REINFORCEMENT**

The term “reinforcement” refers to the ability of an interlayer to better distribute the applied load over a larger area and to compensate for the lack of tensile strength within the road pavement. As in any reinforcement application, the reinforcing material should be stiffer than the material being reinforced (Rigo, 1993).

If successful, several advantages can result from reinforcing HMA overlays:
- increased tensile strength;
- increased resistance to reflective cracking and bottom-up fatigue cracking;
- increased shearing resistance and hence may reduce shoving and flow rutting;
- increased coherence in the overlay, if placed correctly;
- potential materials savings and enhanced pavement performance.

One of the oldest interface systems used in flexible pavement is steel reinforcement. This idea, which appeared in the early 1950s in the USA, was based on the general concept that if HMA is strong in compression and weak in tension, then reinforcement could be used to provide needed resistance to tensile stresses.

In the early 1980s, a new class of steel reinforcement products appeared in Europe. Many of the problems encountered earlier appeared to have been solved, and satisfactory experiences with the new class of steel reinforcement were reported (Vanelstraete, et al., 2000).
Based on field experiences and numerical simulation, reinforcing mesh has been reported to improve flexible pavement ability to resist rutting and fatigue associated distresses (Vanelstraete et al., 2000).

Laboratory results from Nottingham University also suggested that steel reinforcement might improve the fatigue life of overlay by a factor of up to three (Brown et al., 2001). Utilizing finite element analysis approach, Coni and Bianco (2000) showed the effectiveness of steel reinforcement to significantly reduce reflection cracking. Others, such as Vanelstraete et al. (2000), showed the effectiveness of steel reinforcement in reducing the slab rocking; Vanelstraete and Francken (2000) showed that steel reinforcement is effective in reducing the reflection of cracks; while Veys (1996) reported the superior performance of steel mesh reinforcement in delaying the appearance of the reflective cracking when compared to other interlayer materials.

THE BI-AXIAL DOUBLE TWIST STEEL WIRE MESH EINFORCEMENT

The asphalt reinforcement in discussion is manufactured from double twisted steel wire mesh with transverse reinforcing rods evenly spaced throughout at approximately 16 cm centres, as depicted in figure 3. The hexagonal mesh size is 8 x 10 cm type as defined in EN 10223-3, with mesh wire diameter and transverse rod diameters as 2.4 mm and 4.4 mm respectively. The tensile strength of in machine direction and cross machine direction are 40 kN/m each. The wire is protected against corrosion by a GalMac coating complying with EN 10244-2 Class A. The thickness of the product varies between the 2.4 mm wire diameter up to 9.2 mm where the transverse rod passes through the double twist. The varying height of the product strands, and distance between them, ensures that the asphalt can encapsulate the wire, without developing a weak shear zone at the product interface.

DESIGN WITH BI-AXIAL DOUBLE TWISTSTEEL WIRE MESH

**General Design Approach:** The design of the bi-axial double twist steel wire mesh followed is an empirical mechanistic process and is based on the research commissioned by the UK highways agency, which resulted in a design software for reinforced overlays and is currently used for designing asphalt reinforcement in several projects.

![Figure 3. Bi-axial double twisted steel wire mesh](image-url)
The software is a predictive programme which is suitable for use in overlay design and which uses a linear elastic crack fatigue model derived from research and modelling at Nottingham University in the UK.

This programme has been extensively trialled and is capable of replicating test results from both semi-continuously supported beam tests and the pavement test facility. The resulting predictions are of the same order as those from the CAPA finite element programme, developed at Delft University. This programme offers the flexibility required to cope with the highly complex problem posed by reflective cracking and the effectiveness of reinforced asphalt in extending the life of the pavement.

In Nottingham university research, two principle tests were conducted, comparing glass fibre, polymer and bi-axial double twist steel wire mesh grids with an unreinforced control sample. The semi-continuously supported beam test replicates the distribution of stress cracking through pavements. The results showed that reinforcement can significantly enhance the resistance of asphalt to crack propagation, with bi-axial double twist steel wire mesh being particularly effective, offering a life enhancement factor of up to 3.

The Nottingham Pavement Test Facility was used to demonstrate the behaviour of reinforced pavements under wheel load traffic conditions: the thickness of the asphalt was designed to generate a level of strain under wheel loading which would result in cracks developing relatively quickly. In controlling ruts, bi-axial double twist steel wire mesh performed in a similar manner to the polymer grid, offering an improvement factor of approximately 2.

The design input requires the definition of the elastic moduli of the layers in the existing pavements and in the overlay, and the traffic. The output is a fatigue life for the unreinforced and reinforced pavements. It is important to note that this empirical model is mechanistic and based on specific reinforced asphalt research data, and therefore will not generate the same fatigue life results calculated by using other linear elastic empirical models. However, if the life of the critical layer is calculated by other means, then this life can be treated as equivalent to the unreinforced fatigue life value calculated by our model, and the benefit of the reinforcement applied using the same improvement factor value (Pezzano et Al, 2017).

**Design for Safawi-Iraqi border road project:** The predictive software developed from Nottingham university research program, following an empirical mechanistic process was used in the design of asphalt reinforcement in this project. The final pavement details considered in the program in given in table 1.

<table>
<thead>
<tr>
<th>Road layer type</th>
<th>Thickness (mm)</th>
<th>Stiffness (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wearing course</td>
<td>70</td>
<td>4000</td>
</tr>
<tr>
<td>Base course</td>
<td>50</td>
<td>900</td>
</tr>
<tr>
<td>Sub-base course</td>
<td>340</td>
<td>110</td>
</tr>
<tr>
<td>Subgrade</td>
<td>--</td>
<td>57</td>
</tr>
</tbody>
</table>

For the given traffic conditions, it was predicted that the adoption of the steel mesh asphalt reinforcement could achieve an improvement factor of 5.99 with a resulting overlay life of 25 years.
against 5 years without asphalt reinforcement for same thickness. Refer figure 4 for the plot of propagation of cracks in the overlay design. Figure 5 presents the details of the final thickness of the pavement considered in the design program and the position of the asphalt reinforcement.

**Figure 4. Plot of crack propagation in overlay design**

**INSTALLATION DETAILS**

The following simple installation procedure was adopted

Step 1: Milling of top 14 cm thick bituminous layers

Step 2: Seal all the cracks with a suitable crack sealant

**Figure 5. Final design layer thicknesses with asphalt reinforcement position**
Step 3: Unroll and fix the bi-axial double twist steel wire mesh on the milled surface by nailing

Step 4: Apply tack coat required for bonding of new overlay with the milled surface

Step 5: Apply the new 7 cm thick overlay layer made of Polymer Modified Bitumen

Figure 6. Milling and sealing of cracks for Safawi-Iraqi border road project

Figure 7. Asphalt reinforcement deployed for whole width of the roadway
CONCLUSIONS

The adoption of biaxial double twist steel wire mesh asphalt reinforcement in the Safawi Iraqi border rehabilitation project was the first of its kind in Jordan. This innovative approach resulted in many advantages to the project stakeholders. Some of the direct and important merits to list are, increase of design life of the rehabilitated road, increase in construction speed, decrease in number of detours required etc., in addition to the indirect benefit of environmental friendliness of the solution and reduction in carbon footprint emission owing to the reduction in thickness of new bituminous layers by 5cm for a 11m wide road stretch of 20km length. The reference of steel mesh-based asphalt reinforcement technique in Safawi Iraqi border project in Jordan clearly throws light to understand the problems associated with the design and construction of old road rehabilitation projects in the Middle East region, and how such innovative design and construction approaches can be successfully adopted, avoiding expensive and time consuming conventional design solutions that relies on significant thicknesses of both milling and reconstitution.

REFERENCES


