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Full Length Research Paper

Asphaltic concrete facing for rockfill dams in arid and semi-arid countries: A case study of Alsourani Dam, Syria

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Asphaltic concrete lining for dams and storage reservoirs are today classified as state of the art technology. Storage reservoirs and dams are sealed with asphaltic concrete –world-wide. However, certain prerequisites are absolutely necessary for the successful use of this sealing method. First, there must be careful selection and suitability testing of the construction materials and then the subsequent elaboration of the mix composition for the various layers of the lining package. Professional placement and careful compaction are the critical impotence for the quality of finished lining. Asphaltic concrete as an impervious material is used in many countries for more than 60 years. In the Arab region, the asphaltic concrete is used in Syria, Oman, Algeria, Iraq, UAE and Saudia Arabia for sealing of dams and storage reservoirs. The first use of asphaltic concrete in Syria was the sealing of Al Sourani dam in Tartus by the use of asphalt facing with inclination of 1:2.25. The construction of the asphalt facing was finished in November 2003. In this paper, we shall explain the property of the construction materials, lining design, quality control, and thermal condition in such semi-arid area.

Key words: Asphalt, dams, testes, construction materials, bitumen.

INTRODUCTION

Nowadays, linings for dams are usually manufactured from asphalt. This type of sealing also proves to be advantageous in the case of large dams for irrigation water, drinking water, and water for industrial uses. Asphaltic linings are also suitable for replacing or over-laying old sealing made of concrete or mineral materials, which have become less efficient for one reason or another. Asphalt is a mixture of bitumen and mineral aggregates. With a suitable composition, if professionally placed, asphaltic concrete can be manufactured in such a way that it is waterproof.

The advantageous characteristics of an Asphaltic lining in relation to its basic requirement, namely impermeability to water that: It can absorb pressure forces as well as bending and shearing forces, and up to a certain limit, it is compatible with regard to consolidation settlements. To a certain extent, as a result of the visco-elastic characteristics of the bitumen, tensile stresses in the film of the bonding agent between the adjacent grains of mineral can be reduced without the development of cracks. This feature, exploited in the asphaltic linings with large areas, can be produced without seams.

In cases where there will be a particular load on asphaltic lining with regard to ductility, stability, low-temperature behavior and frequent load alternation, the characteristics of the bitumen and thus the mix, can be improved by adding many additions as fiber glass (Mahrez and Rehan, 2010) and plastics etc.

Asphaltic mixes can be composed in such a way that in addition to the desired consistency and flexibility, they also have sufficient suitability to be placed on slopes with an inclination of up to 1:1.3, (Schoenian, 2000). The first use of the asphaltic concrete in Syria was the sealing of Al- Sourani Dam in Tartous by the use of asphalt facing with an inclination of 1:2. 25. The construction of the

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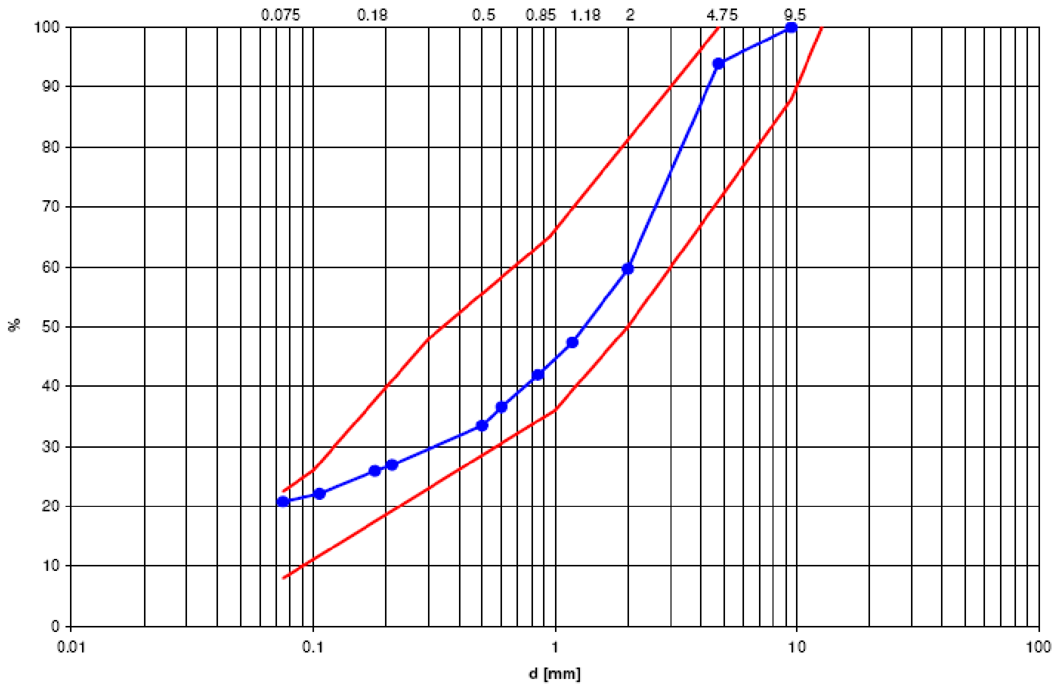


Figure 1. The grain-size distribution for the used aggregates in AL-Sourani dam (d(mm), passing (%)).

asphalt facing was finished in November 2003.

In this paper, we shall explain the property of the construction materials, lining design, quality control, and thermal condition such semi-arid area.

CONSTRUCTION MATERIALS

Bitumen

The usual classification of bitumen in grades is done according to penetration. In fact, this represents the viscosity at a certain temperature (Geiseler, 1996). It is the value in 1/10 mm, by which a needle loaded with 100 g penetrates the bitumen at 25°C in 5 s. In hydraulic engineering, bitumen with a penetration range of 50 and 70 is usually designated as B65, and penetration of between 70 and 100, designated as B80.

The penetration of the bitumen used in Al-Sourani Dam was 71. It has also the following properties: Ductility of 150 mm and ring and ball at 65°C.

Mineral aggregates

The mineral aggregates should be from healthy rock, free of all swell able components and with a good affinity to bitumen. Impact shatter values and compression strength are not important as in road engineering (Geiseler, 1996).

Fillers <0.09 mm, manufactured sand, natural sand of 0.09 to 2 mm, crushed aggregates in sizes of 2/5 mm, 5/8 mm, 8/11 mm, 11/16 mm and if needed 16/32 mm for drainage layers, are used. The ratio of bitumen to filler by weight is approximately 1:2) (ICOLD, 1999).

The aggregates used for Al-Sourani Dam were from healthy rock and area near Lattakia (Rassion). The grain-size distribution for the used aggregates is shown in Figure 1 for impervious layer.

LINING DESIGN

The cross section of the asphalt facing used in Al-Sourani Dam is shown in Figure 2 (Ludewig, 1992; ICOLD, 1999). This type of lining is called uncontrolled system; it means, the seepage during the asphalt facing cannot be measured. It consists of:

1. Asphaltic mastic seal coat approximately 1 to 2 mm (70% filler+30% bitumen) (ICOLD, 1999) .
2. Impervious asphaltic concrete course (25 cm).
3. Asphalt binder course (0 to 25 mm), thickness 10 cm.
4. Bituminous emulsion 2 kg/m^2.
5. First transition layer (0 to 56 mm), thickness 100 cm.
6. Second transition layer (0 to 32 mm), thickness 100 cm.

Guideline for the design and execution of asphaltic linings in hydraulic engineering is the recommendation for the execution of asphaltic work in hydraulic engineering "(EAAW, 2008).

QUALIFICATION TESTS

Qualification tests must demonstrate, on a Marshal specimen compacted with an effort comparable to that achievable on site, that a final void content in a range well below the maximum value of 3% volume. It is attainable (Asbeck and Baron, 1968).

Final compaction by the rollers will vary according to mix temperature, slope and equipment used for the considered project. In the design of the mix, the number of Marshal Blows on each side of the specimen must be adapted to the compaction that finally can be expected with the equipment. It is the responsibility of the contractor to select the right number of blows to represent the compaction effort achievable in practice on the slope.

From experience, it is known that the number of blows can vary between 7 and 35 (schoenian, 2000). The number of blows should always be stated when the void content of a sample prepared in the laboratory mix is given.

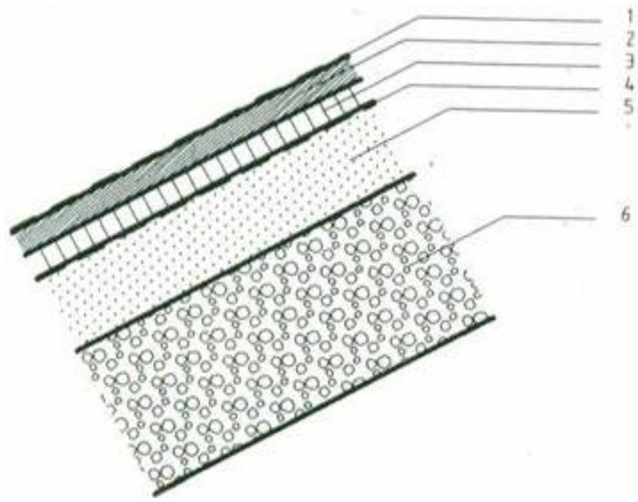


Figure 2. The cross section of the asphalt facing used in Al-Sourani Dam (uncontrolled system) (ICOLD ,1999).

The weight of the roller used in Al-Sourani Dam was about 5 ton and the marshal blows were 30.

In the qualification tests, mix compositions of aggregate and bitumen were tested with (Shoenian, 2000):

(1) 8 different amounts of bitumen, with increments of 0.5, 7, 8, 9, 9.5, 10 and 10.5%.
(2) 3 specimens were made for each bitumen content, and compaction was carried out with the standard Marshal hammer.
(3) The specimen was weighed in air and in water to determine the mass density of the compacted mix.
(4) At each bitumen content, the following mix properties were determined (average of the three specimens):

a. Marshal stability and flow.
b. Voids in the mineral aggregate in the compacted Asphalt specimen V (ma).
c. Air voids of the compacted Asphalt specimen (VA).
d. Mass density of the compacted Asphalt specimen ρA

These properties were entered into Figure 3a to e. The V (ma) for hydraulic mixes with sufficient bitumen contend will normally be positioned just beyond the minimum on the rising branch of the curve and it must be less than 22% (Shoenian, 2000).

While the mass density ρA will be positioned just beyond the maximum on the falling branch (Shoenian, 2000), the bitumen content must be so-coordinated in such a way that, on one hand, there is a sufficient coating of the mineral particles, and on the other hand, the stability on slope is guaranteed.

The optimal bitumen content is a function of the type of aggregate employed, of the necessary workability of placing temperatures, of the layer thickness and required service life (Ludewig, 1992). Figure 3a to e shows the relationships between bitumen content and marshall stability, flow, density, V (ma) and void content.

From Figure 3a to e, the optimal content of bitumen was selected to be 9% and the air void was about 1.66%; Marshall stability = 7.37 KN, V(ma) = 21.6%, Marshall flow = 8.17 mm, density = 2.28 g/cm^2.

OTHER MIX PROPERTIES

Table 1 shows the requirements for impervious layer (Ludewig, 1992)

SPECIAL TEST METHODS

Flexibility tests

To test the flexibility of asphaltic layers, an apparatus was manufactured for this purpose described in (Shoenian, 2000; EAAW, 2008) where the sample was exposed to water pressure equivalent to the water height upstream of the dam, the thickness of the sample was, as shown in Figure 4, about 50 mm and the diameter 500 mm. The space below the test specimen was only partially filled with sand, so there was free space left. The partial filling forms a saucer with depth (h) equal to one tenth of the diameter (s) of the trough (h/s = 1/10). The pressure was increased in the way described in Shoenian (2000) and EAAW (2008) and consequently the sample remained quite impermeable.

Slope stability tests for asphaltic concrete mixes

Determination of maximum temperature of the asphalt facing

Temperature has been measured in many depths in an experimental area that was built near the location of the dam site which has the same inclination (1:2.25), the measurements were taken for two consecutive years. The dimensions of the experimental area are 30 m length and 20 m width located at the right river bank and in the southern direction, so it receives the maximum sun radiation.

The maximum temperature on the surface was about 60°C during the measuring period, also the temperature in many depths related to the above maximum and air temperature were measured. To obtain the maximum temperature which may occur, a mathematical-physical model was established through which the maximum expected temperature could be calculated on the surface of the asphaltic facing and at various depths. This model depends on the energy budget equation at the surface of the asphaltic facing (Al chiblak, 1989; Djemili et al., 2005). The model requires climatic information such as air temperature, atmospheric pressure, air turbidity, etc. as well as geographic information such as latitude, height above sea level, etc. and information related to properties of heat transfer of asphaltic concrete. The researcher has written a special computer PROGRAM for solution the energy budget equation.

The aforementioned model and the respective program with the actual measures performed in the experimental area were tested and results showed good conformity between the calculated values through the model and the measured values in the experimental area (Djemili et al., 2007). For determining the maximum temperature of the asphaltic concrete which may be exposed, search was made for the highest air temperature in the dam area during fifty-year period and this temperature was 41°C.

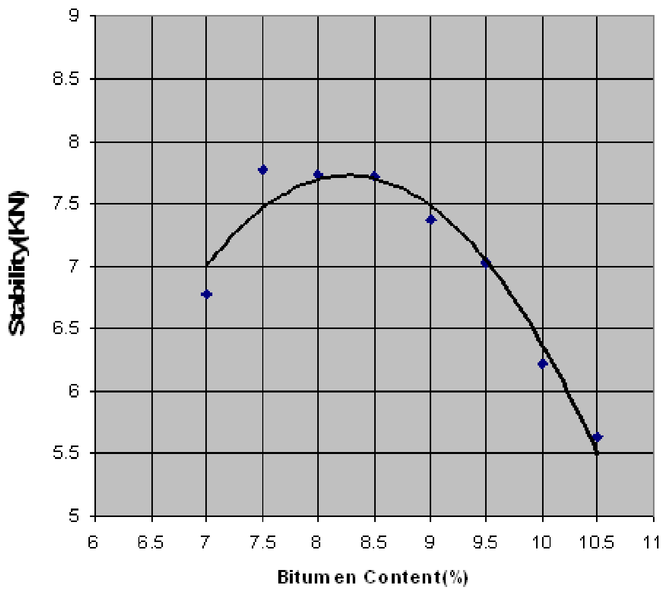
Other accidental climatic conditions that lead to maximum temperature were also indicated.

By using the mathematical-physical model, the maximum temperature that could occur once every fifty-year period was calculated and it was about 73°C and temperature was also calculated on various depths of the asphaltic facing as illustrated in Figure 5.

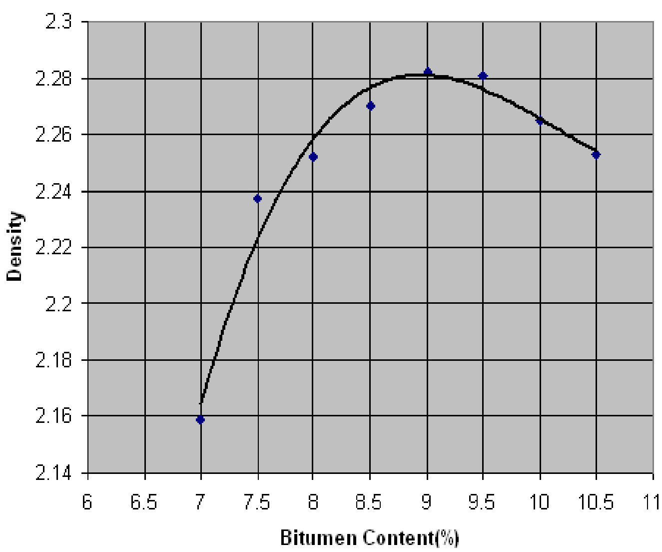
The experimental area was also used for selection of the suitable roller weight and Marshal blows. The selected roller weight was 5 tons and the selected blows were 30 tons.

Stability test

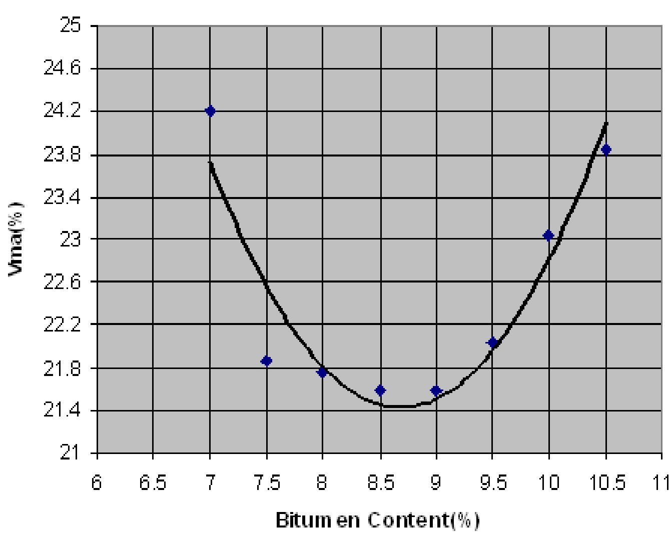
For testing slope, stability (Shoenian, 2000; EAAW, 2008) showed an apparatus as shown in Figure 6. As a simpler method, it is recommended to take Marshal specimens, cut them in two half-cylinders and store them for 48 h in an oven at a highest ambient

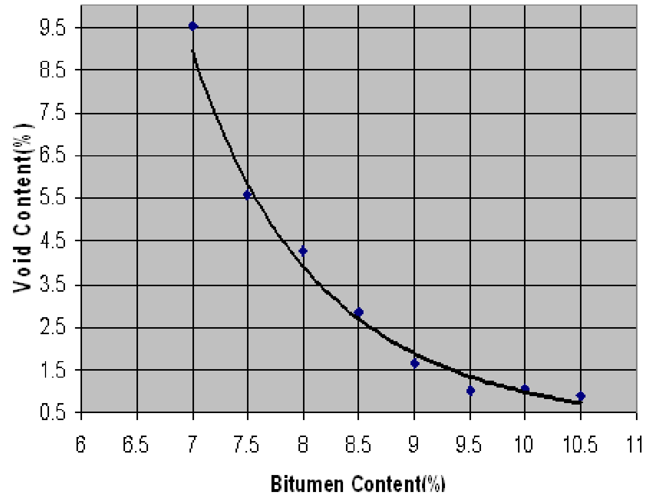


(a)



(b)





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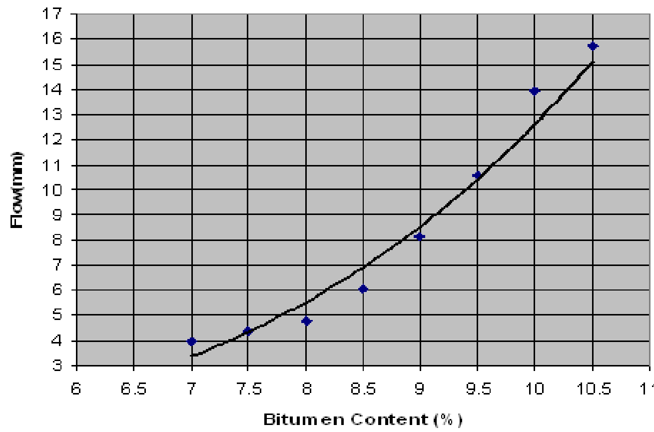

(e)

Figure 3. Relationship between (a) Marshal stability, (b) densities of Marshal specimen, (c) V(ma), (d) void content, (e) flow after Marshal; and bitumen content.

temperature to be expected (for Al-Sourani Dam in Syria at 73°C), the specimens were taken from the executed layers and were placed on a tilted plated with the inclination of the projected structure (1:2.25) and held by a metal strip of about 1 mm high, the rest of the cylinder height of ca.65 mm being free to deform.

Deformation of the specimen was small within the first 24 h and not further increase substantially during the second 24 h, so we can say the layer is stable on the slope (Shoenian, 2000; EAAW, 2008). The frequency of quality control testing was more than required by USSG (2011).

SITE INSPECTION

During the execution period, specimens were continuously taken from the asphaltic mix and from executed layers after compaction. The void content and the mass density were determined. Experimental results showed that the values of void content were less than 3% of the specimen taken from the executed layers and laboratory specimens prepared by using the hot mix. The average rate of compaction was more than 97%.

Permeability factor of specimens of the executed layer was also

Table 1. The requirements for impervious layer (Ludewig, 1992).

S/N	Property	Permissible value	Experimental value
A	**Basic requirement**		
1	Compression strength		
	At temperature 20°C- R20	30	55
	At temperature 50°C- R50	15	20.15
	At temperature 0°C- R0	-	126.43
2	Coefficient of thermal stability Kt = R 20/R 50	2-2.5	2.734
3	Coefficient of water resistance after test performed in vacuum.	>0.9	0.92
4	Coefficient of elasticity Ke=R0/R20	2-2.8	2.295
5	Coefficient of permeability (cm/s)	<10E-7	6.8×10E-8
B	**Supplementary requirements**		
1	Water absorption in % of the volume.	<1.5	0.3
2	Swelling in % of the volume.	<0.5	0.038
3	Bond index of the asphalt with the surface of mineral aggregated	>90%	95%
4	Marshal stability	>6 KN	7.37 KN
5	Marshal stability after 14 days water laying down.	5.4 KN	6.7 KN
6	Flow according to Marshal.	(4-8 mm)	(8 mm)

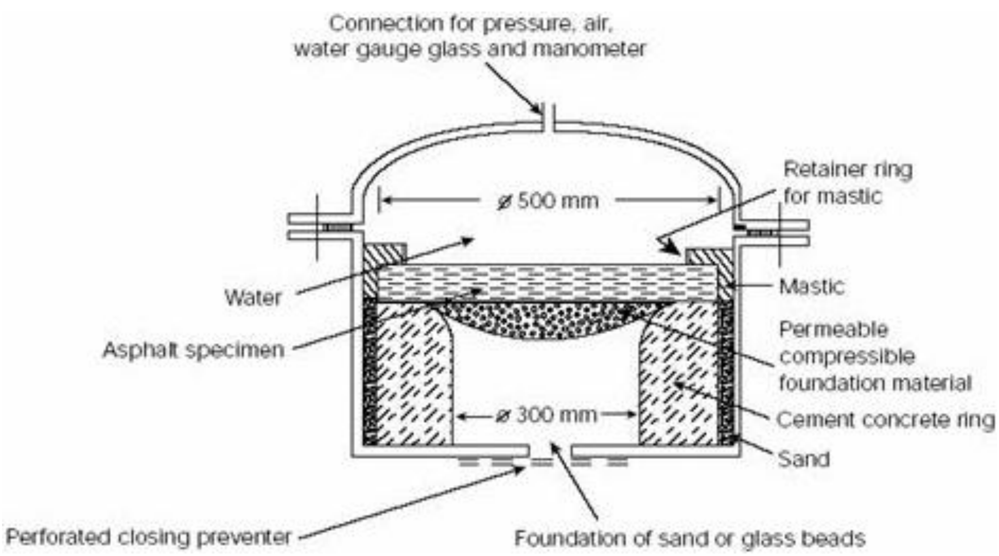

Figure 4. Illustrating the used apparatus that was manufactured according to Shoenian (1999) and Ludewig (1992).

indicated and the average value of six specimens was 4.2×10^{-8} cm/s.

Grain-size distribution was also controlled many times per day and the abnormal mixes were refused.

VISUAL CONTROL AFTER DAM FILLING

Because the used type for the asphalt sealing is uncontrolled system, it was impossible to separate the seepage components, but after dam filling in winter 2003 up to April 2009, the seepage from the dam and underground is decreased and not increased. We have not seen any fissured areas or concentrated seepage from the dam. The asphaltic facing showed a good behavior and no creep features.

RESULTS AND DISCUSSION

The experimental results in the labortatory and after spreading and compaction showed that the required

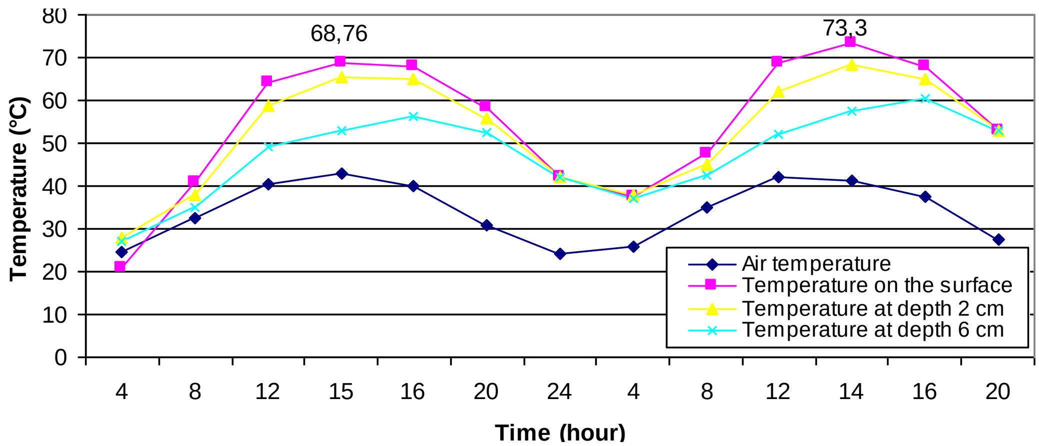

Figure 5. Temperature changes in the asphaltic concrete facing Al-Sourani dam.

Figure 6. Equipment for testing deformation characteristics of a compacted asphaltic concrete mix on slopes.

characteristics of the mixture are suitable if its grading curve (or aggregate curve's) is positioned inside the beam illustrated by Figure 1. Particularly the void ratio and the permeability are considered as essential characteristics of asphaltic layer for sealing purposes.

During the study and design of mixture, the goal was to have low porosity (lower than 3%) by making the choice of a grading curve included in the beam shown in Figure 1 and by a good choice of the ratio filler / bitumen, which also offered good mechanical characteristics to the mixture. A mixture, having porosity lower than 3%, resists the weather influences better.

The stability experiments on specimen and the visual control after dam filling proved that no deformations were detected, that means the choice of filler/bitumen ratio was good.

The specimen compaction in the laboratory showed that the preparation of the laboratory samples with 30 blows of Marshall was an adequate choice comparing with available instruments at the site.

During compaction, the simultaneous adjustment of the speed of the compaction instrument and the cord of traction, were essential to avoid all deposit of mixture under the wheel.

Conclusion

Asphaltic concrete linings for dams are today classed as state of art. Many dams are sealed with asphaltic concrete world-wide also in the arid and semi arid countries. Alsourani dam was the first dam sealed with asphaltic concrete in Syria, and it is in operation since 2003 until now.

However, prerequisites are absolutely necessary for successful use of this sealing method. First, there must be careful selection and suitability testing of construction materials and then the subsequent elaboration of the mix compaction for the various layers.

Professional placement and careful compaction are of critical importance for the quality of finished lining. Moreover, continuous control of the construction material, mix and layer placed is imperative.

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