HYDRAULIC RESISTANCE MORTAR

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ABSTRACT:
Erosion and impact are one of the biggest problems in hydraulic structures. Erosion is caused due to cavitation, abrasion & chemical attack (e.g. sulphate or soft water in granite rock zones); while impact is due to repeated chocks from stones and debris carried out in the discharged water. Various systems can be used to mitigate these issues such as steel plating, fibre reinforced concrete, epoxy resin, acrylic and polymer concrete or repair mortar coating.

These systems have advantages and inconvenient – most of the time, inconvenient taken over the advantages (cost, difficulty in placing, durability, etc.)
The paper describes a cement based resurfacing mortar Sika MonoTop®-3400 Abraroc with very high resistance to hydraulic abrasion and an improvement to it to further resist to severe impact. It is has been developed years ago and has proven its efficiency in term of cost versus performances and durability for restoration of various elements in dams normally spillway, aprons, stilling basins, sluiceways etc.
Some references will also be presented from various part of the world

1. Typical issues encountered in hydraulic structures

Some's of the biggest challenges in hydraulic structures are erosion & impacts. There are various causes to erosion like:

- Erosion by cavitation
- Erosion by abrasion
- Erosion by chemical Attack

Impacts are caused by the transportation of heavy stones and metallic object

1.1 Erosion by cavitation

Cavitation is the formation of bubbles or cavities in a liquid. In hydraulic structure, the liquid is water, and the cavities are filled with water vapour and air. The cavities form where the local pressure drops to a value that will cause the water to vaporize at its ambient temperature. Concrete surface irregularities can trigger the formation of these cavities.

Picture 1: *Typical example of cavitation*

1.2 Erosion by Abrasion

__Picture 2:__ Typical example of erosion by abrasion in a spillway of a small dam.

This damage is the results from the abrasive effect of waterborne silt, sand, gravel, rocks and other debris being circulated over a concrete surface during operation of a hydraulic structure. Abrasion erosion is readily recognized by the smooth, worn-appearing concrete surface, which is distinguished from the small holes and pits formed by the cavitation erosion. Spillway, aprons, stilling basins, sluiceways and tunnel linings are particularly susceptible to abrasion erosion.

1.3 Erosion by Chemical Attack

__Picture 3:__ Typical example of soft chemical attack in an irrigation canal

The compounds present in hardened Portland cement are attacked by soft water, by sulphate and many salt and acid solutions. Acidic or sulphate environments can result in deterioration of exposed concrete surfaces. The acidic environment can range from low acid concentration found in many river to high acid concentrations found in many processing plant. Soft water leaches out the mineral compounds from the cement matrix.

1.4 Impact

__Picture 4:__ Example of metallic element found in an energy dissipation basin in China

The detrimental effects of erosion and impact can be controlled by

- designing structure to minimize cavitation effect
- Using aeration to control damage
- Hydraulic consideration
- Using suitable material

2. Typical Suitable Materials

2.1 Steel Plating

Steel plating is a very effective method to resist erosion. But in some occasion, it can be impractical to install not mentioning the cost of such material and its installation (e.g. in a spillway)

2.2 Fibre Reinforced Concrete

This method is cost effective to replace either partly or entirely damaged concrete. Inserted fibres help to dissipate the energy during the chocks.

However, in many occasion, using this method may results in increase frequency of the rehabilitation due to a limited expected durability.

2.3 Epoxy Mortar

This type of product may provide some durability but the placing can be challenging in a damp environment as generally epoxy mortars are sensitive of substrate moisture.

2.4 Acrylic/polymer concrete or repair mortar

These repair methods may be cost effective as the polymer modification may improve the ductability of the repair material.

However, standard repair material may be quickly eroded by abrasion if the formulation is not adapted.

2.5 Ideal Suitable Materials

The ideal suitable repair material shall be:

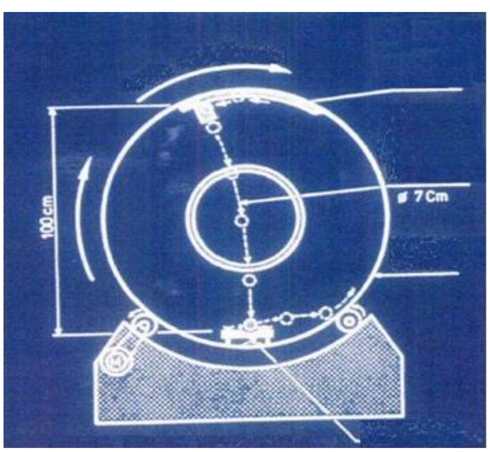
- Not sensitive to the humidity of the substrate,
- Resistant to chock and impact
- Resistant to abrasion
- Mild chemical resistant (e.g. sulphate, mild acidic and soft water resistant)
- Application either manually for small area (e.g. to repair cavitation) or by spray method for large area (e.g. to repair spillway)
- And finally but not least, cost effective

3.1 Impact Test

To determine the suitability of a repair material to withstand erosion by abrasion, this material can be tested using an impact test

The testing machine elaborated by the CNR (Compagnie National du Rhone – leading company in the building & maintenance of dam in France) is intended to reproduce in laboratory the impact conditions encountered in the hydraulic structures.

The basis of this impact test is as shown below. A metallic ball of 7 cm diameter and of 1 kilogram mass fell from a 1 meter height onto the sample to be tested with a frequency of 15 impacts per minutes. The total number of impact at the end of the test is 2 700.



Recovery slide channel

Path of the metallic ball

Rotary drum

Concrete specimen

Picture 4: *Schematic drawing of impact test – source by CNR*

The test consists in:

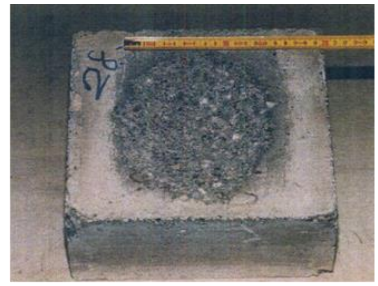
- Measuring the volume of the print
- Measuring the variation of the cohesion of the material at the print level and to compare this cohesion to the situation before the impact – this is done using coring test.

The values are recorded as follow:

The index is equal to the volume of the print in cm^3.

The following values are given in as typically obtained:

- Granite: < 100 cm^3
- Very resistant concrete: < 150 cm^3
- Resistant concrete: 150 to 250 cm^3
- Typical B25 concrete: 250 to 400 cm^3
- Inferior concrete: > 400 cm^3



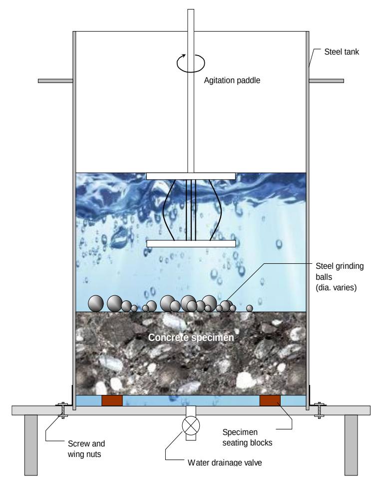
Picture 5: *Impact test result on typical B25 concrete*

3.2 Hydraulic resistant test

3.2.1 ASTM C 1138 Abrasion Resistance of Concrete (underwater method)

It was developed to recreate the abrasive action of waterborne particles in hydraulic structures.

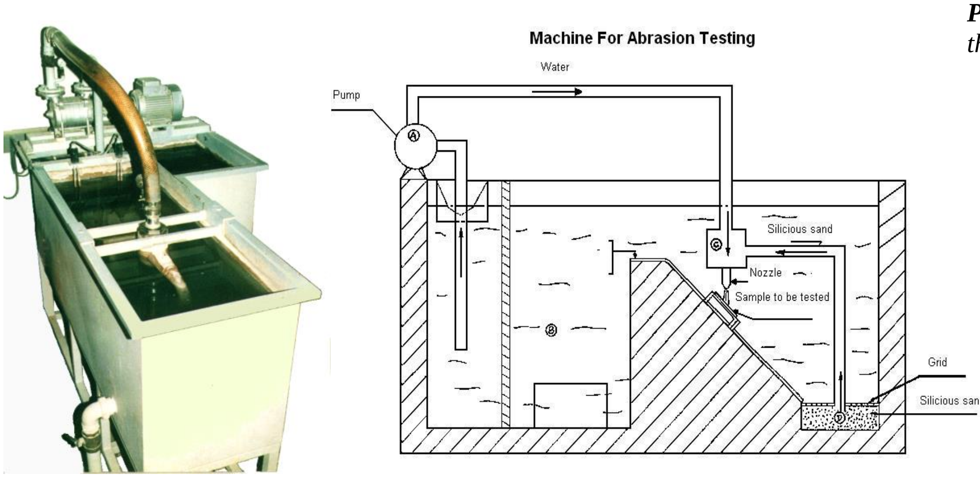
- Concrete specimen subject to erosion abrasion under the action of steel grinding balls.
- The steel grinding balls are propelled on water in the test chamber.
- The water is in turn propelled by a submerged mixer paddle.
- Water velocity/: ~2m/sec
- The damage is quantified and the lost material is reported as a percentage of original mass



Picture 6: *Schematic drawing of the ASTM C 1138 test*

3.2.2 CNR Method

The testing machine elaborated by CNR is intended to reproduce in laboratory the impact conditions encountered in the hydraulic structures.



Picture 7: *Photo and schematic drawing of the CNT hydraulic abrasion test method*

This method combines the abrasion damage by cavitation and erosion due to waterborne particles.

The test consists in injecting a mixture of water and sand under pressure (2.5 bars) at an angle of 45° directly on the concrete specimen and to leave it running during 75 minutes. The measure consists in taking the volume print of the test specimen comparatively to a block of glass (30 mm thick). This lay out allows appreciating the wear resistance by abrasion of the tested material in the form of an abrasion index:

I = V/ Vo

V	=	Print volume of the sample
Vo	=	Average print volume of the glass block

This Index is then defined in relation to glass. This index allows comparing materials. The lowest the index, the best is its abrasion resistance

Typical values are obtained:

▪ Control (glass block):	1.00
▪ Granite:	0.35 to 0.80 (depending on the source)
▪ Very resistant concrete to abrasion:	< 1
▪ Resistant concrete to abrasion:	< 2
▪ Traditional B25 concrete	2 to 3
▪ (with calcareous silica aggregate)	
▪ Concrete with low resistance to abrasion:	3 to 4
▪ Inferior concrete:	> 4
▪ Steel and cast iron:	0.02 to 0.04

3 Sika MonoTop®-3400 Abraroc

In collaboration with the CNR and Sika France, a special mortar with very hard silica aggregates was developed in the late 80’s and the performances were as follow:

Resistance to Erosion by Cavitation:
CNR Index: 0.35 to 0.5 (Equivalent to a block of granite)

Resistance to Erosion by Abrasion:
Impact resistance: Two time better than plain B25 concrete

Resistance to Chemical Attack:
pH >4: Resistant
Sulphate : Resistant (Low sulphate cement and silica fume technology)

4 Impact

In some projects, heavier resistance to impact is required – refer to enclosed picture 8.

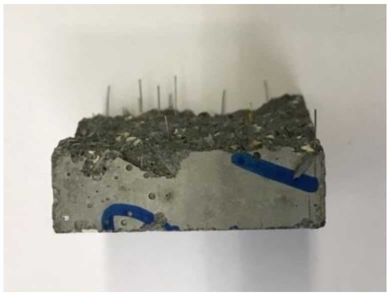
As the performance of this mortar is only twice the performance of a grade 25 N/mm^2 concrete, it is doubtful that it could support such impact stress.

***Picture 8:** Uptake channel*

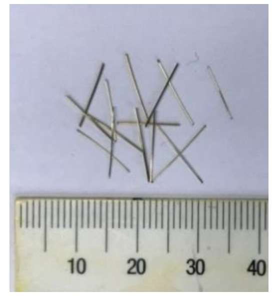
A full study was recently performed in the central laboratory of Sika in

Switzerland, to assess the benefits brought by the addition of tiny steel fibres on the Sika MonoTop®-3400 Abraroc.

In case of such severe environment as shown in picture 8 above, it may be necessary to improve the capacity to absorb energy and resist to impact especially if, for cost aspect, only a topping of 50 mm is used on top of newly applied concrete.



Picture 9: *Distribution of the fibres in the harden mortar*



Picture 10: *Steel fibres*

4.1 Testing program

Reference concrete:

- Concrete C0.45: As per EN 1766 Type C0.45 with max. aggregates size of 16 mm
- Mortar MC0.40: As per EN 1766 Type MC0.40 with max. aggregates size of 8 mm
- Concrete C0.67: As per EN 1766 Type C0.70 LF with max. aggregates size of 16 mm
- Mortar MC0.70: As per EN 1766 Type MC0.70 with max. aggregates size of 8 mm

Sika MonoTop®-3400 Abraroc mixing ratio: 2.8 kg of water per 25 kg bag

Steel fibres: 13x0.23 mm; dosed at 300 g per 25 kg of Abraroc

Bonding layer: Epoxy adhesive Sikadur®-30

Age of concrete reference at the time of the application of the bonding bridge: 1 day

Time between the bonding bridge and the application of Sika MonoTop®-3400 Abraroc: 2-7 minutes

Curing of the specimens (for the tests 1 to 4): 20°C 95% RH (after demoulding)

Curing of the specimens (for the tests 5): 20°C 65% RH (after demoulding)

Curing of the reference concrete specimens (tests 6 & 7): 20°C 95% RH (after demoulding)

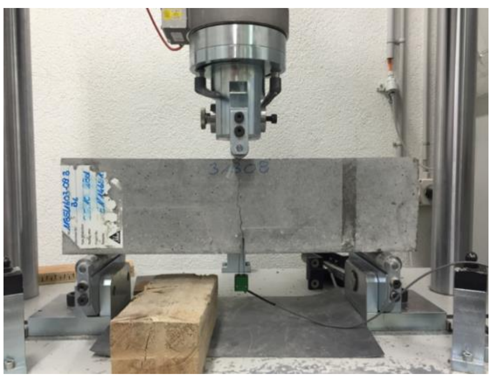
Curing of the build-up specimens (reference & Abraroc – tests 6 & 7): 20°C 95% RH (after demoulding)

For the flexural tensile strength and energy absorption capacity tests, the build-up of the test sample reproduce a typical site application of a 50 mm topping on top the existing concrete

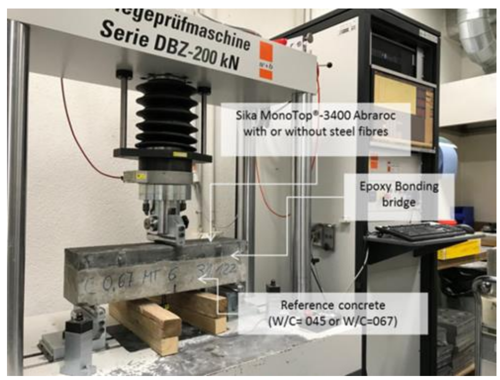
Test		Standard	No. samples	Sample sizes [mm]	Remarks
1	Flexural tensile strength	EN 14651	3	150 x 150 x 600	▪ 100mm Concrete / 50mm Abraroc ▪ 100mm Concrete / 50mm Abraroc with Steel fibres ▪ Concrete C0.45 / C0.67
2	Energy absorption capacity	EN 14488-5	3	600 x 600 x 100	▪ 50mm Concrete / 50mm Abraroc ▪ 50mm Concrete / 50mm Abraroc with Steel fibres ▪ Concrete C0.45 / C0.67

4.2 Flexural tensile strength

The tensile behaviour of metallic fibre mortar is evaluated in terms of residual flexural tensile strength values determined from the load-crack mouth opening displacement curve or load-deflection curve obtained by applying a centre-point load on a simply supported notched prism. The Abraroc build-up specimens are compared to the respective plain reference concretes.



Picture 11: *Flexural tensile strength testing of reference concrete*



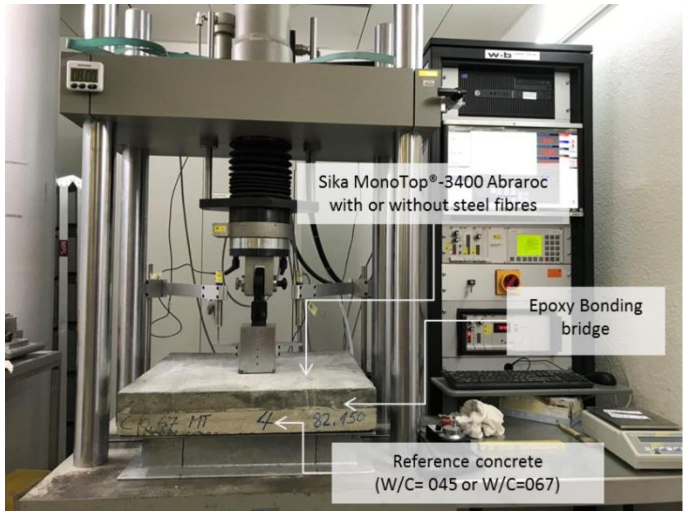
Picture 12: *Flexural tensile strength testing of Sika MonoTop®-3400 Abraroc Build-up*

4.3 Energy Absorption Capacity Test

EN 14488-5 is the standard to measure the energy absorption capacity of fibre shotcrete. Therefore the application procedure has been modified to accommodate the casting of concrete and the Sika MonoTop®-3400 Abraroc build-up. A square specimen is produced (dimensions of 600 mm x 600 mm with a thickness of 100 mm for the reference concrete; for the Abraroc build-up: 50 mm of reference concrete and 50 mm of Abraroc with or without fibres).
A part of the placing procedure, the procedure of testing follows the specified standard.
After hardening, the fibre reinforced slab specimen is subjected to a load, under deflection control, through a rigid steel block positioned at the centre of the slab.
The load-deflection curve is recorded and the test is continued until a deflection of at least 30 mm is achieved at the centre point of the slab.
From the load-deflection curve a second curve is calculated giving the absorbed energy as a function of the slab deflection.

The Abraroc build-up specimens are compared to the respective plain reference concretes.

Picture 13: *Testing of reference concrete*



Picture 14: *Testing of Sika MonoTop®-3400 Abraroc Build-up*

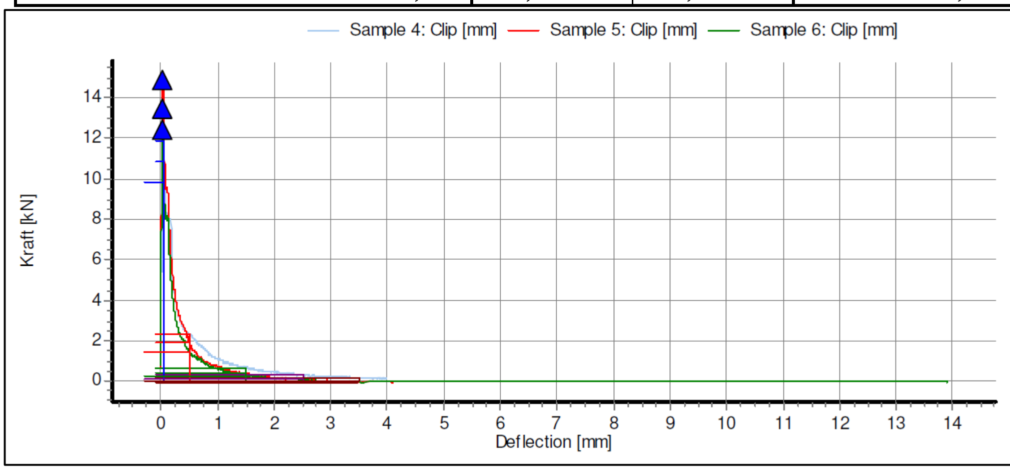
4.4 Results

4.1.1 Flexural tensile strength

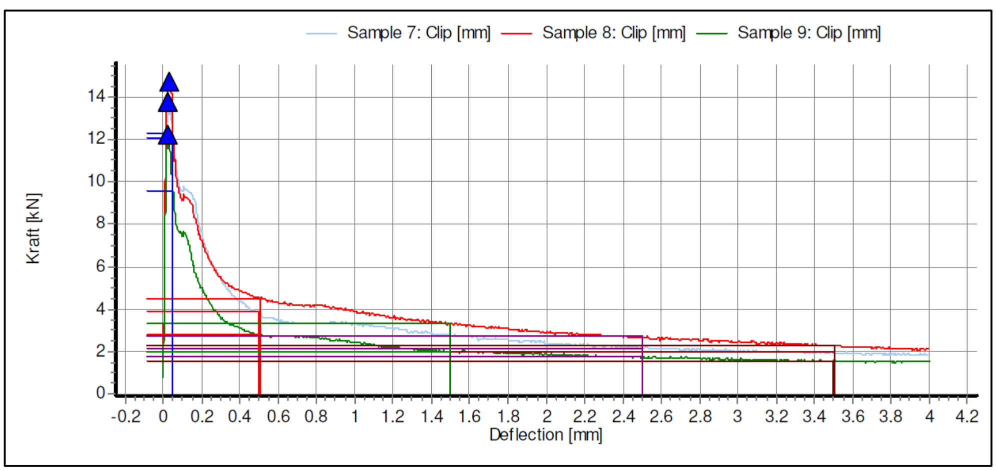
Average value of 3 specimens	MT-3400 Abraroc + C0,45		Reference concrete	Unit
	No Fibre	With Fibre	C 0.45	
Limit of proportionality (LoP); $f_{ct,L}$	4,35	4,35	4,57	MPa
Bending strength residual; f_{R1}	0,61	1,2	0,41	MPa
Bending strength residual; f_{R2}	0,15	0,86	0,09	MPa
Bending strength residual; f_{R3}	0,05	0,7	0,04	MPa

Bending strength residual; f_{R4}	0,02	0,61	0,03	MPa
Standard Deviation; f_{R1}	0,14	0,28	0,12	MPa

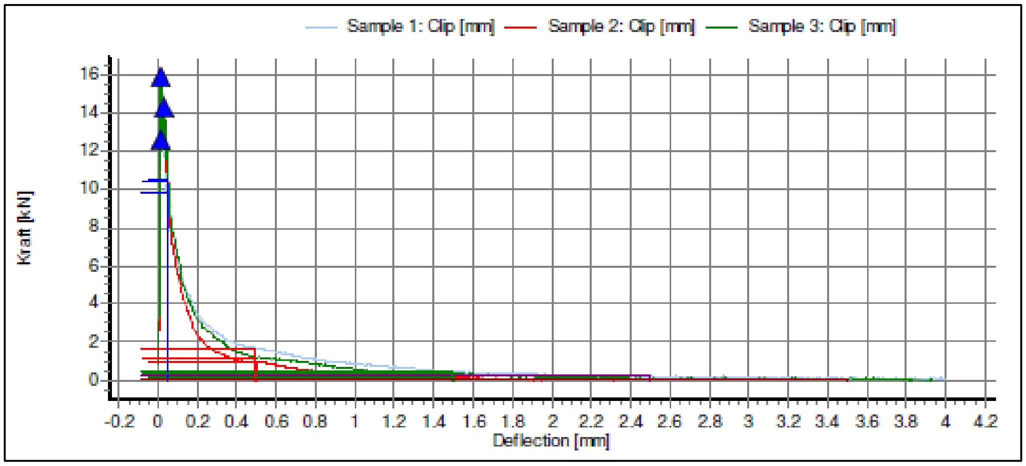
Average value of 3 specimens	MT-3400 Abraroc + C0,67		Reference concrete	Unit
	No Fibre	With Fibre	C 0.67	
Limit of proportionality (LoP); $f_{ct,L}$	3,73	3,39	3,80	MPa
Bending strength residual; f_{R1}	0,66	0,96	0,46	MPa
Bending strength residual; f_{R2}	0,24	0,80	0,17	MPa
Bending strength residual; f_{R3}	0,11	0,66	0,09	MPa
Bending strength residual; f_{R4}	0,05	0,57	0,06	MPa
Standard Deviation; f_{R1}	0,04	0,19	0,08	MPa



Graph 1: Sika MonoTop®-3400 Abraroc on top of concrete C0,45 – Tensile flexural strength testing



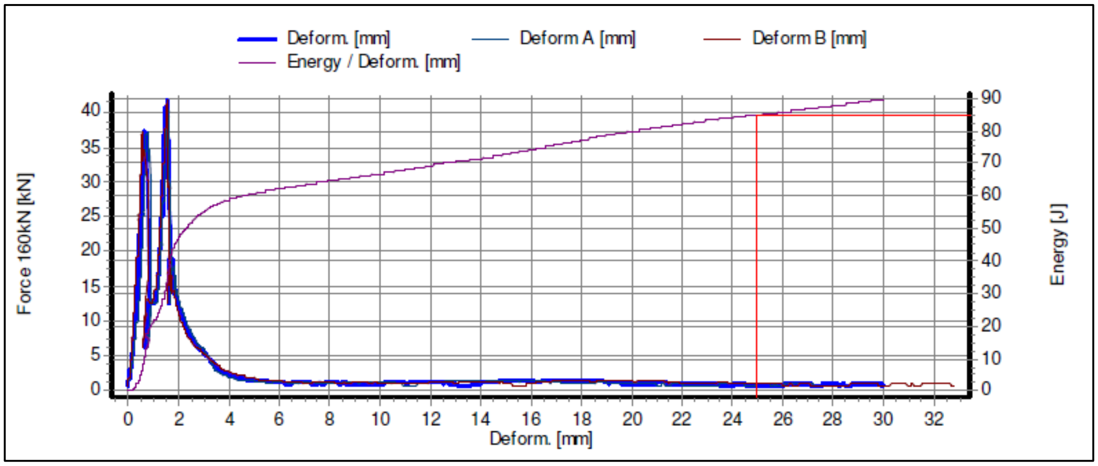
Graph 2: Sika MonoTop®-3400 Abraroc with steel fibres on top of concrete C0,45 – Tensile flexural strength testing



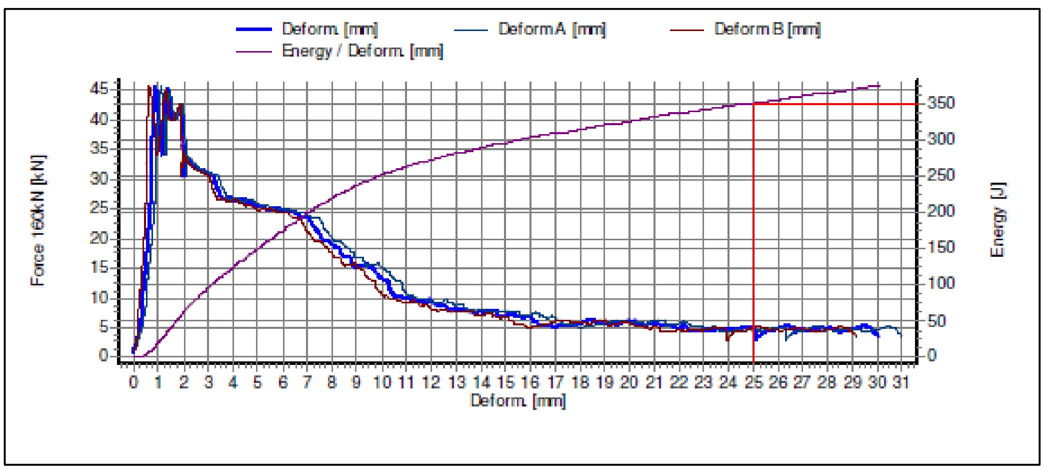
Graph 3: Concrete C0,45 – Tensile flexural strength

4.1.2 Energy absorption capacity test

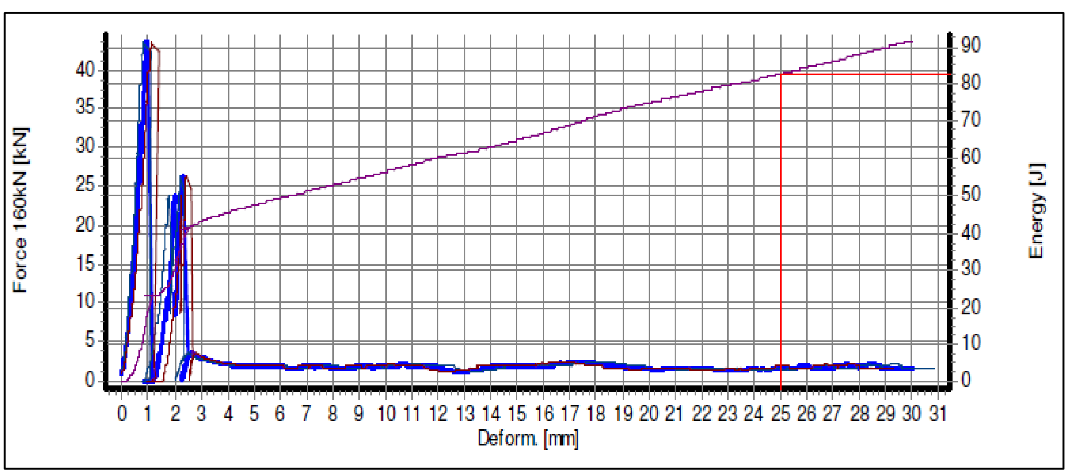
Average value of 3 specimens	MT-3400 Abraroc + C0.45		Reference concrete	Unit
	No Fibre	With Fibre	C 0.45	
Density	2320	2320	2280	kg/m^3
Maximal load, F_{max}	44,7	41,7	38,8	KN
Deflection at maximal load	1,3	1,1	0,9	mm
Energy absorption by 25 mm, E_a	100	300	90	J
Energy absorption total, E_{tot}	100	310	100	J
Standard Deviation; E_a	12	61	23	J
Aspect at break	Typical failure AND no sign of delamination of the topping		Typical failure	
Average value of 3 specimens	MT-3400 Abraroc + C0.67		Reference concrete	Unit
	No Fibre	With Fibre	C 0.67	
Density	2280	2270	2310	kg/m^3
Maximal load, F_{max}	38,7	33,4	34,1	KN
Deflection at maximal load	0,8	1,3	0,9	mm
Energy absorption by 25 mm, E_a	90	220	100	J
Energy absorption total, E_{tot}	120	230	110	J
Standard Deviation; E_a	0	10	19	J
Aspect at break	Typical failure AND no sign of delamination of the topping		Tears	



Graph 4: Example of a curve with Sika MonoTop®-3400 Abraroc without Steel Fibre applied on concrete C0.45



Graph 5: Example of curve with Sika MonoTop®-3400 Abraroc with Steel Fibre applied on concrete C0.45



Graph 6: Example of a curve with concrete C0.45

5 Case Studies

Sika Abraroc SR (former name of the existing Sika MonoTop®-3400 Abraroc) – Bentong Dam, Malaysia
The product was applied in 2000.
Site was visited with the consultant who was following the rehabilitation, after 15 years of application in August 2015

- ✓ Dam was in operation (having the usual flow of water).
- ✓ Overall condition of dam and spillway looks generally good and suffers no noticeable/severe concrete deterioration.
- ✓ Areas of spillway where Sika Abraroc SR had been applied show no signs of product defect.
- ✓ Hand patch repair section (mortar) shows no signs of defect.

6 Conclusion

For normal protection as seen in the Malaysian project where abrasion was the most prominent issue, Sika MonoTop®-3400 Abraroc is fit for purpose.

However when there is a requirement of heavy impact load resistance, it is important to add some steel fibre to the topping – doing so the capacity to absorb energy hence to resist to impact is more than 3 times a good quality concrete – the same apply to the flexural tensile strength where the build-up with the Abraroc with the steel fibres is also 3 times the plain good quality concrete.

7 References

- Erosion of Concrete in Hydraulic Structure – ACI 210R-87
- ASTM C 1138
- CNR Laboratory
- M. Donadio, Sika Services AG. Technical article – Sika MonoTop®-3400 Abraroc – influence of steel fibres – dated December 2018