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EPDM gaskets; new materials and procedures for segments and other application in tunneling

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ABSTRACT: Sealing systems for various applications such as TBM's segments, shield driven tunnels and various types of pipe jacking have been developed; they are used for roads, rail and metro infrastructures, as well for cable, service, water and sewer projects. One of the latest product which has been designed is a seal that's anchored into the concrete, performing segment production and gasket installation easier and faster without manpower added and adhesive cost, shortened the process due to time savings for the grooved area cleaning, with relevant corner keystone protection advantages, with a quality insurance granted in line not only with the modern times but also with the new Industry 4.0 construction process integration. The article will describe also a different tunnel application in Metro Milano (starting seal) and with the biggest EPB-TBM presently running in the world St. Lucia (culvert seal), referring as well about a special device related to the 30 ton culvert handling procedure.

1 INTRODUCTION

Since many years, Algaher has been delivering a wide range of sealing profiles for various tunnel excavation techniques, following not only the STUVA recommendations but also new Standards under development in EU and USA which are regulating the usage of new composite materials.

Sealing systems for various applications such as segments for tunnel boring machines (TBM), shield driven tunnels and various types of pipe jacking have been developed, as well gaskets for TBM starting, emergency, door and caisson seals. They are used for roads, rail and metro infrastructures, as well for cable, service, water and sewer projects.

One of the latest product which has been designed, in several models and with different optional added devices, is a seal that's anchored into the concrete during the tunnel segment production process. This system is performing segment production and gasket installation easier and faster without manpower added and adhesive cost, shortened the process due to time savings for the grooved area cleaning, integrated link between concrete and seal with relevant advantages on the corner keystone protection, with a quality insurance granted in line not only with the modern times but also with the new Industry 4.0 construction process integration.

Algaher Group is a family company founded in 1984 with the purpose of manufacturing rubber profiles; it is specialized in the manufacture of segmental lining sealing gaskets suitably designed for all kind of tunnels. It develops solutions depending on the needs of each project by four main types of product (Figure 1):

1. Glued gaskets
2. Integrated Gaskets

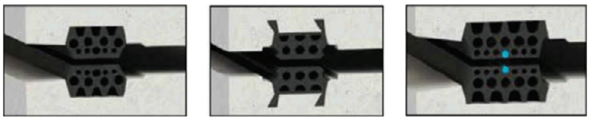

Figure 1. Some rubber profiles.

3. Gaskets with hydrophilic profile
4. Co-extruded gasket

2 WHAT IS EPDM?

EPDM rubber (ethylene propylene diene monomer rubber), a type of synthetic rubber, is an elastomer characterized by a wide range of applications. This is an M-Class rubber where the 'M' in M-Class refers to its classification in ASTM standard D-1418; the *M* class includes rubbers having a saturated chain of the polyethylene type. Dienes used in the manufacture of EPDM rubbers are dicyclopentadiene (DCPD), ethylidene norbornene (ENB), and vinyl norbornene (VNB). EPDM rubber is closely related to ethylene propylene rubber: ethylene propylene rubber is a copolymer of ethylene and propylene, whereas EPDM rubber is a terpolymer of ethylene, propylene and a diene-component (Figure 2).

The ethylene content is around 45% to 85%. The higher the ethylene content, the higher the loading possibilities of the polymer, better mixing and extrusion. Peroxide curing these polymers gives a higher crosslink density compared with their amorphous counterpart. The amorphous polymer is also excellent in processing. Processability is very much influenced by their molecular structure. The dienes, typically comprising from 2.5% to 12% by weight of the composition, serve as sites of cross-links when curing with sulphur and resin; with peroxide cures, the diene (or third monomer) functions as a coagent, which provides resistance to unwanted tackiness, creep, or flow during end use.

EPDM is compatible with polar substances, e.g. fireproof hydraulic fluids, ketones, hot and cold water and alkalis. It is incompatible with most hydrocarbons, such as oils, kerosene, aromatic, gasoline as well halogenated solvents. EPDM exhibits outstanding resistance to heat, ozone, steam and weather. It is an electrical insulator.

Typical properties of EPDM vulcanizates are given below. EPDM can be compounded to meet specific properties to a limit, depending first on the EPDM polymers available, then the processing and curing method(s) employed. EPDMs are available in a range of molecular weights [indicated in terms of Mooney viscosity ML(1+4) at 125 °C], varying levels of ethylene, third monomer, and oil content.

The main mechanical and thermal EPDM's properties are:

- Hardness: 40–90 Shore A
- Tensile failure stress, ultimate: 25 MPa
- Elongation after fracture in %: ≥ 300%
- Density: can be compounded from 0.90 to >2.00 g/cm^3

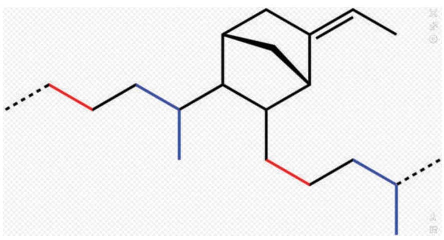

Figure 2. Idealized EPDM polymer, red = ethylene-derived, blue = propylene-derived, black = ethylidene norbornene-derived.

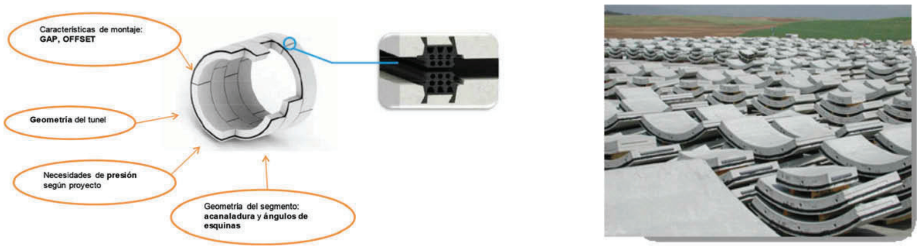

Figure 3. EPDM gaskets and seals in tunneling and tubing sector.

- Coefficient of thermal expansion, linear: 160 µm/(m·K)
- Maximum service temperature: 150 °C
- Minimum service temperature: −50 °C
- Glass transition temperature: −54 °C

A common use is in vehicles: door seals, window seals, trunk seals and sometimes hood seals. Frequently, these seals are the source of noise due to movement of the door against the car body and the resulting friction between the EPDM rubber and the mating surface (painted sheet metal or glass). Other uses in vehicles include cooling system circuit hoses where water pumps, thermostats, EGR valves, EGR coolers, heaters, oil coolers, radiators and degas bottles are connected with EPDM hoses, as well as charge air tubing on turbocharged engines to connect the cold side of the charge air cooler (intercooler) to the intake manifold.

EPDM rubber is used in seals, for example in cold-room doors since it is an insulator, as well as in the face seals of industrial respirators in automotive paint spray environments. EPDM is also used in glass-run channels, radiators, garden, and appliance hose, tubing, pond liners, washers, belts, electrical insulation, vibrators, O-rings, solar panel heat collectors and speaker cone surrounds. It is also used as a medium for water resistance in electrical cable-jointing, roofing membranes (since it does not pollute the run-off rainwater, which is of vital importance for rainwater harvesting), geomembranes, rubber mechanical goods, plastic impact modification, thermoplastic, vulcanizates and many other applications. Colored EPDM granules are mixed with polyurethane binders and troweled or sprayed onto concrete, asphalt, screenings, interlocking brick, wood, etc. to create a non-slip, soft, porous safety surface for wet-deck areas such as pool decks and as safety surfacing under playground play equipment (designed to help lessen fall injury).

EPDM application in tunneling is related to whatever seal (gasket) in the tubbing and segment sector (Figure 3). In case of hydrocarbons presence (for example heading in contaminated areas) it can be protected with a sort of shield, entering in the field of a composite product.

3 PRODUCTION PROCESS

Algaher has a 5000 m^2 plant of manufacture on a 15,000 m^2 extension, equipped with the most advanced technology for the production of this kind of profiles. The area of production is composed by 3 lines of extrusion and by 10 injection equipment, which provides the company of a really relevant production capacity.

The lines of extrusion have a length up to 70 meters where the raw material pass different phases of production (Figure 4):

1. Extrusion and molded
2. Oven for radiation (microwave)
3. Oven for convection (gas)
4. Machine of automated cut

The whole process of extrusion is governed by automatic systems to assure the control of thickness in all the profiles manufactured.

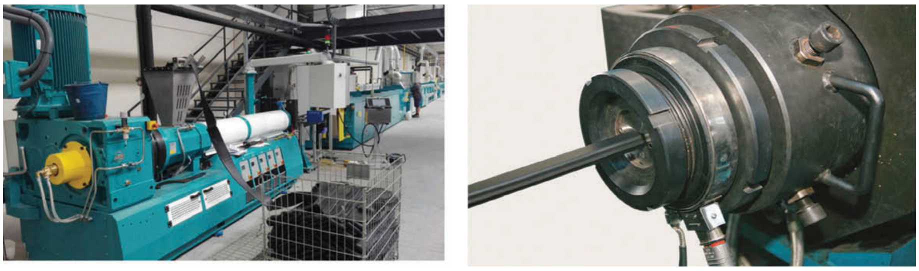

Figure 4. Production line.

The injection equipment has a capacity up to 350 cc per cycle and are provided with all the necessary controls for the manufacture of this kind of profiles:

1. Control of temperature of the mould
2. Control of temperature of mixture
3. Control of vulcanization time.

4 PRODUCTION CONTROL

Internal quality control is a key topic in all kind of industries; Algaher has an own laboratory where the tests and quality controls are realized in all manufactures produced under usual norm of application as the EN 681-1:1996. The internal LAB, besides other equipment, is provided with certified Micrometer, Heater, Durometer and Dynamometer.

The technical department is the one in charge of realizing Analysis of Stress FEM (Method Finite Elements) to estimate the behavior of the internal designs and to come up to the configuration that offers the values target.

It is also clear that the whole traceability of all the products has to be guaranteed during the production processes (Figure 5).

ALGAHER has spaces in order to realize tests of water tightness with different GAP and OFFSET, according to STUVA's recommendations (Figure 6).

All the tunneling water tightness gaskets have (and should have) these internal tests:

– Test: Load – Displacement # Method: STUVA
– Test: Water tightness # Method: STUVA

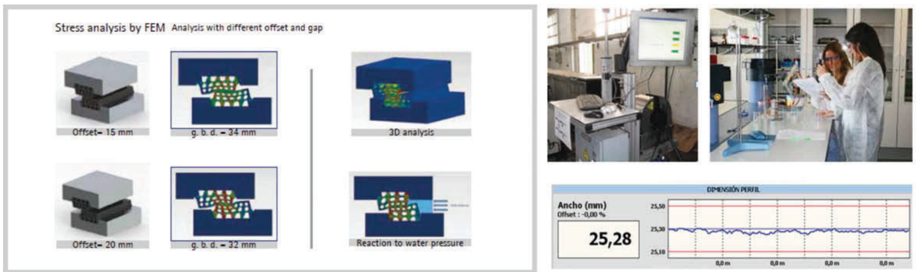

Figure 5. FEM analysis, traceability and Lab.

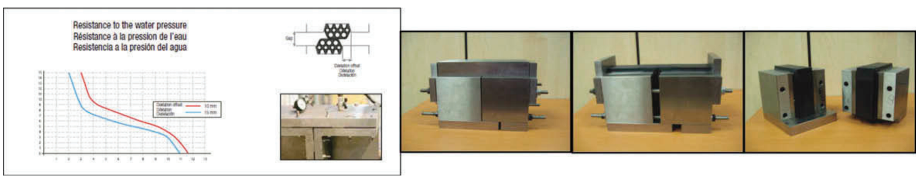

Figure 6. STUVA test devices and results.

– Test: Stress relaxation at 23ºC and 70°C # Method: Iso 3384
– Test: Hardness IRHD # Method: ISO 48
– Test: Traction resistence # Method: ISO 37
– Test: Elongation at break # Method: ISO 37
– Test: Remaining deformation by Compression # Method: ISO 815
– Test: Variation after aging in air durig 7 days at 70 ºC (Hardness – Resistence – Elongation) # Method: ISO 188
– Test: Stress relaxation in compression (7 days at 23 ºC - 100 days at 23 ºC) # Method: ISO 3384
– Test: Volume variation after water immersion (7 days at 70 ºC) # Method: ISO 1817
– Test: Ozone resistance to the at 40 ºC, 50 ppcm 48 hours # Method: ISO 1431-1

5 WATER TIGTHNESS IN CORNERS

Each Manufacturer, usually designs their products in function of customers' needs and in relation to its own experience and they should be calculated to reach high sealing characteristics. One of the gasket key technical point is related to the water tightness in corners; they are designed and manufactured in Algaher and have some technical and competitive advantages:

1. Specific sharped to create a perfect interface between corners.
2. Central nerve specially designed to confer to the "corner" a high resistance.
   As result, the gasket corners reach values very raised in parameters of water tightness.
3. Corners with "Twisted Angle";
   They must adapt perfectly to any obtaining a perfect union between mould and gasket.
4. Corners injected with profile cut at 45 º.

In this way it is obtained a minor quantity of material in the injection without changing either the force of retention or the performance of water tightness (Figure 7).

Another leading factor is related to the special treatment anti-friction "NO GRIP". All water tightness gaskets lodged at the key piece (K) and in the adjacent segments, are provided with a special lubricant thus in order to ease the slide between the gaskets with the purpose to avoid damages between them (Figure 8).

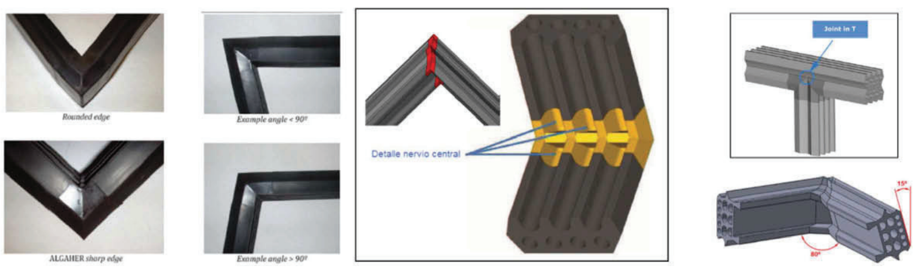

Figure 7. Water tightness in corners.

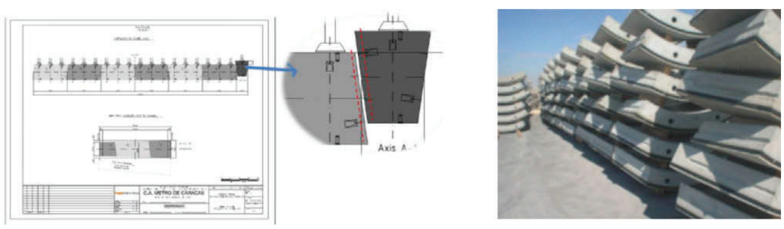

Figure 8. Anti friction "NO GRIP" in Metro Caracas.

6 STARTING TBM SEAL IN METRO MILANO

Metro Blu, consortium between Salini-Impregilo and Astaldi S.p.A., incharged for the excavation of various new Milan Metro line stretches, had and is having the problem to launch various TBMs in a down town environment with the big disadvantage of water table presence at around ground zero! Start boring with a TBM in such a condition is not an easy job.

A special water proof system needed to be designed, using a steel frame and starting seals which consist usually of three parts: seal profile, filler profile and U-channel (Figure 9).

Starting seals are mounted on a special support frame on the tunnel starting ring, as a watertight seal at the gap between the tunnel excavation line and the TBM. For greater water-tightness, several starting seals can be installed in series. When this is done, profile butt joints should be staggered from one seal to the next. Starting seals are fastened into a U-channel without screws or bolts.

They are designed in function of the pressure which have to resist; normal values are starting from 0,5 up o 6 bars and the choice depends on the technical requirements and tunnel diameter.

It is most practical to mount the starting seal before installing the support frame. The seal is laid out to mate with the support frame and pressed into the U-channel, one portion (ca. 50m) at a time. If used, filler profile is pressed in simultaneously, locking the seal profile into position.

Usually when all but the last 75 cm of the starting seal has been installed, the remainder is cut to an extra length of 50 mm and installed. This additional length creates pressure on the profile butt joint, providing an adequate seal.

For eventual added water-tightness, adhesive is applied to the butting surfaces, following the adhesive manufacturer's application instructions. It is recommended to position the butt joint at the top of the support frame to minimise hydraulic pressure on the joint during boring.

Various type of Sealing Ring Lip Seals, in accordance to the Client's specification and under Algaher's experience suggestions, have been successfully installed (Figure 10).

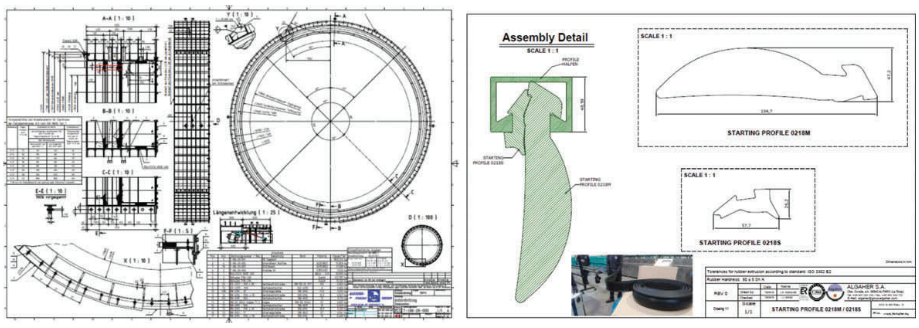

Figure 9. Steel frame design and starting seal.

Figure 10. Installation and start boring in different stations.

7 CULVERT SEAL IN ST. LUCIA

On the highway A1 (Milan-Napoli), huge tunnelling jobs are under execution since years, in order to modernize and power the old route. Santa Lucia tunnel represent the principal job which is creating a new highway line in the South direction. Few main data are:

- Owner: Autostrade per l'Italia S.p.A
- Main Designer: SPEA S.p.A.
- Contractor: Pavimental S.p.A.
- Tunnel length: 7548 m
- TBM excavation diameter: 15,965 mm
- Excavation surface: 199 m^2
- Excavated volume: 1,480,000 m^3 fully handled automatically trough a complex belt conveyor system designed and manufactured by the well known Marti Technik.AG
- Lining type: universal precast ring in 9 + 0 elements, length: 2.2 m, thickness: 55 cm and 16 ton of weight for each element
- Geology: Monte Morello limestone and Sillano clay, with potential presence of Methane gas.
- Job duration: 1852 days
- Job start: 15th March 2016
- Job finish: 9th April 2021
- TBM excavation average speed: 9 m a day (28 months is the finishing time foreseen)

The TBM, in EPB mode, is the biggest in the world presently in operation and the n. 2 ever built. The weight is in the range of 4800 ton.

The 200 m^2 section will host 3 highway lines (3.75 m width), plus platform and plants and a huge precast safety tunnel has been designed above the vehicles running deck.

No. 2830 bi-cell precast concrete culverts measuring 2.83 m long x 7458m wide x 2.90m high having a 32 tons weight are currently, manufactured at the same casting yard of the tunnel lining, to be fitted under the road deck.

The seal designed is the Delta 24, having in section 24 x 42 mm dimensions, 14,67 m in length, with round corners, 45°±5° sH, under EN 681-1/CE norms. The essential characteristics, Performance and Harmonised technical specification are:

- Dimensional: L3 – E1, ISO 3302
- Hardness: 45 ± 5, UNE EN 681-1:1996
- Tensile strength: Min. 9 MPa, UNE EN 681-1:1996
- Elongation at break: Min. 375 %, UNE EN 681-1:1996
- Compression set 72 h. at 23 ºC: ≤ 12, UNE EN 681-1:1996
- Compression set 24 h. at 70 ºC ≤ 20, UNE EN 681-1:1996
- Compression set 72 h. at -10 ºC ≤ 40, UNE EN 681-1:1996
- Ageing 7 d. a 70 ºC, Hardness change max: +8/-5, UNE EN 681-1:1996
- Ageing 7 d. a 70 ºC, Tensile strength change max. -20 % UNE EN 681-1:1996
- Ageing 7 d. a 70 ºC, Elongation at break change max: +10/-30, UNE EN 68-1:1996

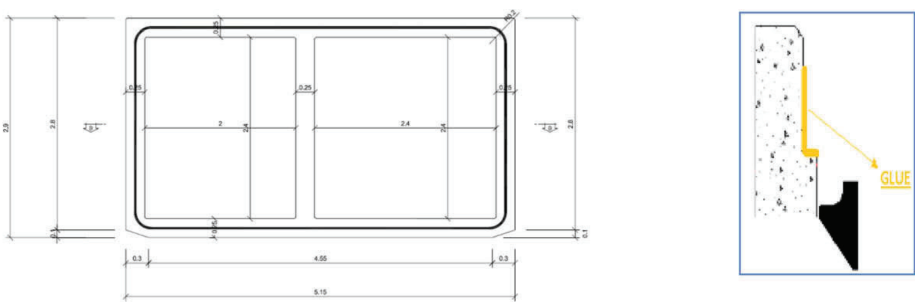

Figure 11. Culvert dimension in section.

– Stress relaxation, max. 7 days at 23 ºC: 16 %, UNE EN 681-1:1996
– Stress relaxation, max. 100 days at 23 ºC: 23 %, UNE EN 681-1:1996
– Volume change in water, 7 days al 70 ºC max:. +8/-1 %, UNE EN 681-1:1996
– Ozone resistance: No cracking, UNE EN 681-1:1996

7.1 *Culvert gasket & handling procedure*

The Culvert prefabrication, seals application, culvert handling and installation is quite complex and very well designed by the technical team lead by Maccafaerri Tunnelling S.r.l., company which is realizing such elements for Pavimental S.p.A, Algaher SA and CP Technologies S.r.l. who has been the brain engine to design and manufacture all the mechanical devices to let the full system work perfectly (besides the fact that CP Technologies has as well delivered the full carousel, segment moulds, external structure, lifting devices, aerial concrete distributor lines, electronic control . . . in a full integrated Industry 4.0 environment).

First of all, the elements are casted with a stationary hydraulically operated mould, allowing the casting and demoulding operation aimed by a very special demoulding and tilting device. A safe and controlled Algaher's procedure is used to fix the gasket in the right position (Figure 12)..

A very interesting matter is the culvert's handling procedure from the prefabrication area, which is ca. 50 km far away from the Santa Lucia job site. The culvert once cast, demoulded, turned at 90 degrees (Figure 13), finished with installation of the sealing gasket is than loaded on a truck to be transported at site.

Here it is offloaded by a portal crane and transported in the tunnel by MSVs. CP-Technology has developed a self-propelled culvert laying gantry with integrated vehicles ramps (Figure 14) easing at the same time the transit of heavy pay load vehicles, suitably designed to be driven inside lined tunnel, thus to lay behind the operating TBM the prefabricated concrete culverts.

Figure 12. Culvert cast in situ, rotation device and gasket installation.

Figure 13. Culvert demoulding and turning device.

Figure 14. Culvert handling procedure from the casting yard to the job site and along the tunnel.

Separating the culvert-laying gantry from the TBM backup is a new idea. The pros and cons of adopting such a technique are:

Pros:

- Individual design approach avoiding the need to raise the road to achieve adequate cover
- Typical pre-stressed RC units - Not innovative material = reasonable cheap
- Good fire performance of RC elements
- Quick construction Prefabricated units "ready to use"
- Simple and fast installation
- Culvert-laying gantry directly behind the TBM
- Separate TBM production from culvert-placing production meaning Installation contemporary to the excavation
- Continuous Access/Traffic to the excavation front
- Limited areas of concrete mass fill on sides only
- No shutter (Formwork) needed

Cons:

- Thick Elements
- Multiple Short Spans
- Slow construction progress due to cast in-situ topping

8.1 *Culvert installation procedure*

In details the installation procedures involve the following activities:

Bedding, intended to level out any remaining irregularities on the tunnel lining invert portion and ensuring uniform support under the full width and length of the box culvert including:

a. Lay a thin flat apron of unreinforced lean mix concrete on the invert portion of the lining which has been well prepared to a uniform firmness
b. Lay of thin bed of sand (Figure 15).

Transport of the box culvert (Figure 16) in longitudinal position along the axle of the tunnel, by means of MSV, and stop under the gantry crane.
Lifting of the box culvert by means of the gantry crane and opening of the folding ramp in order to allow the laying of the culvert (Figure 17).
Transport of the box culvert to the installation area by displacing the gantry crane trolley and rotation of the culvert in its final position (Figure 18).
Laying of the box culvert on the already prepared invert surface and closing of the joints by pushing the culvert against the one previously laid. The complex operation is conducted by keeping the weight of the culvert jointed on the crane thus to reduce the frictional resistance at the base of the culvert, easing sufficient compression load to compress the culvert seal, therefore closing the joint to the specified nominal gap (Figure 19).

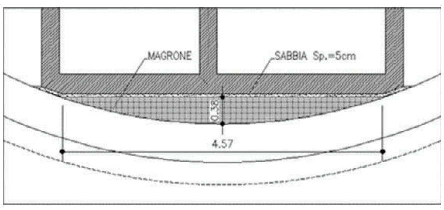

Figure 15. Installed culvert.

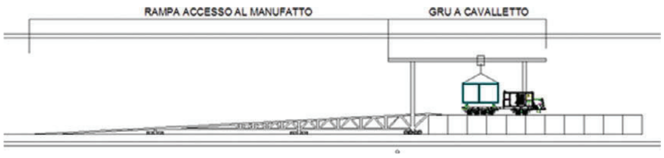

Figure 16. Transport of the culvert by MSV.

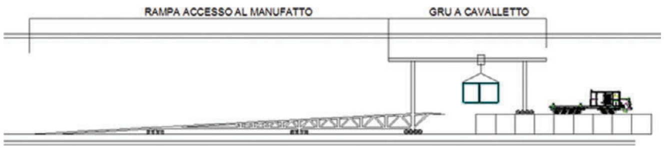

Figure 17. Lifting of the culvert.

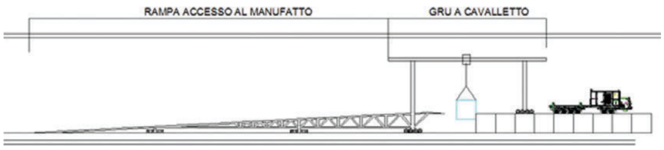

Figure 18. Transport of the box culvert to the installation area.

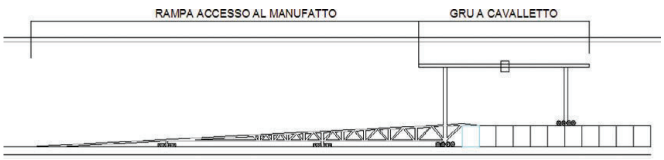

Figure 19. Positioning the culvert into the invert surface.

6. Lifting of the folding ramp and displacement of self-propelled culvert laying gantry to the next bay.
7. Finally Culvert sides shall be Backfilled to the level of the top of the box culvert working evenly on each side using selected backfill material well compacted in layers.

9 CONCLUSIONS

EPDM is a world for Specialists which are called to work in Team; from the "gasket" producer, where it is requested a high level of professionality and a big effort for research and development in order to find always new solutions and advanced material applications in a full quality optic, to the Contractor who is requested to deep analyze problematics, times and methods.

Other "Subjects" are called to play this type of "game"; for example, as we have seen, the Self-Propelled Culvert Gantry operates in accordance to methods and procedures given by the Contractor (studied in Team work session) for the installation of precast concrete box culverts taking careful attention to details, leading to safer working activities, a smoother flow of operations and a higher standard of finished culvert installation.

The complex circle is what is called, at the end, "Industry 4.0"; pull of Specialists, fully integrated for a perfect final product.