Deep Foundations Institute/ Geo-Institute of the A.S.C.E,. New Orleans, February 10 -12, 2003

Irreversible Changes in the Grouting Industry Caused by Polyurethane Grouting: An overview of 30 years of polyurethane grouting

Alex Naudts[1]

Abstract

Water reactive polyurethane grouts were introduced into the grouting industry during the late sixties by the Takenaka Company in Japan under the trade name TACSS. It became possible to inject "one component" grouts without pot life that do not easily wash out and react with the ground water. Because of environmental scrutiny, the first series of TACCS were replaced by solvent-free, hydrophobic, MDI based polyurethane prepolymers. Whilst remarkable successes were booked in mining and geotechnical engineering projects, more and more these products were used for permanent seepage control for sealing concrete structures. Hydrophilic polyurethanes were also introduced in Japan predominantly for the latter application. They contained solvents and were TDI based. Their high reactivity and high dilution ratio with water made them attractive to practitioners.

In 1980, the N.V. DeNeef Chemie obtained the exclusive rights for TACSS for most places on earth and the successes in stopping major leaks in tunnels changed classic grouting (sodium silicate cement combinations) and seepage control grouting (acrylamide grouting) because of practical and environmental considerations. After the N.V. Denys brought similar products to the industry in 1980, more manufacturers jumped on the bandwagon. By the mid-eighties there were more than 10 manufacturers of polyurethane grouts. Several new and improved hydrophobic water reactive urethanes were developed during the eighties as a result of this new trend. A few manufacturers created closed cell, water reactive hydrophobic polyurethanes. The era of custom-made formulations, tailored to the project, started.

Water reactive hydrophilic polyurethanes came under close scrutiny because of longevity problems. The classic two-component polyurethane foams, used in mining were gradually introduced in geotechnical engineering. For permanent seepage control, in concrete structures two component polyurethane elastomers became popular. The introduction of hydro block in France for major inflow control was another remarkable development. Extensive research was performed, especially in Scandinavia to establish life time expectancy of hydrophobic water reactive polyurethane. Pioneering research was done to establish mathematical models to understand the flow of P.U. through fine fissures. This paper focuses on the engineering aspects of polyurethane grouting with in the background the history of these fascinating products. It elaborates on the various types of applications illustrated with case histories for each type.

---

1. Alex Naudts, M.A.Sc. Civ.Eng., P.Eng., President, ECO Grouting Specialists Inc., Amaranth, Ontario, Canada L9W 0J6 Tel. (519)928-5949; ecogrout@ecogrout.com

Background

Polyurethane grouts are probably the most popular type of solution grouts. They have been used for more than 35 years and have contributed to the democratization of the grouting industry.

The term solution grouts pertains to grouts that behave like Newtonian fluids. Contrary to suspensions grouts, which behave like Binghamian fluids, solution grouts do not contain particles. The term "chemical grouts" is misleading, since cement-based suspension grouts are complex chemical grouts too. Solution grouts are injectable into very fine apertures, not accessible to (even microfine) suspension grouts.

Scientific analysis of polyurethane grouting has been under-represented. For too long polyurethane grouting has been considered the business of small time operators only and substantially ignored by the larger practitioners. Polyurethane grouting was once the trade of the finesse grouters (predominantly operating in seepage control work). They in turn, have become a major force in the grouting industry.

Polyurethane grouts encompass a large family of solution grouts. It is therefore very difficult to make generic statements for the entire group. Most polyurethane grouts are non-evolutive or true solution grouts. A true solution grout is characterized by a flat viscosity curve, followed by a sudden increase in viscosity, immediately prior to gelation or curing. Acrylamide, acrylate and most polyurethane based grouts are typical examples of true solution grouts.

The following categories of polyurethane grouts are, in general, recognized by the industry:

- Water reactive polyurethane grouts
- Two component foaming grouts (polyol-isocyanides combination)
- Two component polyurethane elastomers

Water reactive polyurethane grouts in turn have two main sub-categories:

- hydrophobic polyurethane prepolymer grouts
- hydrophilic polyurethane prepolymer grouts

The two aforementioned sub-categories and the two other categories are further divided in sub-families of polyurethane grouts. The sensitivity (i.e. the ability to control factors influencing the reaction or curing pattern during the reaction) of most polyurethane grouts is typically lower than the sensitivity of cement-based suspension grouts.

The longevity of the end product and its chemical resistance are typically far superior than cement-based suspension grouts (Naudts, 1990). The toxicity of most of the polyurethane grouts is usually not an issue and approval for use in potable water applications has been obtained for several polyurethane categories of grouts.

Solution grouts have made it possible to treat media with a measurable permeability, whether wood, glass, masonry, concrete, rock or soils. Because of some irresponsible use of some solution grouts (especially from an environmental standpoint) and their selection for ill-conceived applications, solution grouts have generated some bad publicity in the past. Environmental issues are usually very complex, and often quite controversial, hence solution grouts, unjustifiably have received a bad reputation. Water reactive hydrophobic polyurethane grouts are now commonly used. They are successfully used for seepage control in concrete structures, for soil and rock grouting under flow conditions in mining and for environmental applications.

Polyurethane Grouts: Overview

Water Reactive Polyurethanes: Polyurethane prepolymer grouts have one thing in common: they react with the in-situ available (ground) water to create a foam or gel that is either hydrophobic or hydrophilic. They are "one component" products using "the enemy", the water, as a reaction partner to create the end- product. The catalyst (a tertiary amine) is not considered a component since it only affects the rate and the direction of the polymer forming process (Hepburn, 1992). Adding more catalyst only speeds up the gelation process. Surfactants are added to the resin to prevent collapse of the foam and to create small uniform cells.

Water reactive polyurethane resins are classified into two sub-categories:

- Hydrophobic polyurethane resins: they react with water but repel it after the final (cured) product has been formed.
- Hydrophilic polyurethane resins react with water but continue to physically absorb it after the chemical reaction has been completed.

During the exothermic reaction, the hydrophobic polyurethanes expand and penetrate pervious media: fine cracks (as narrow as 8 micron) and soils (with a permeability coefficient as low as 10-4 cm/s. The penetration is greatly enhanced by the formation of CO_2, independent from the grouting pressure. Hence the name: "active" grouts. Their penetrability is determined by their viscosity and reaction time. Credible research work on the penetration rate of hydrophobic water reactive polyurethane into fine fissures has been conducted by Andersen (1998). Andersen's work reveals that the penetration of fine apertures is a very slow process, which requires multiple hole grouting to obtain a economically justifiable and technically sound grouting operation. The gel time is linked with a rapid increase in the viscosity. Prior to gelation, the viscosity of the grout decreases because of the formation of CO_2. During gelation, the viscosity increases substantially and prevents further penetration.

Hydrophilic polyurethanes form either a gel or foam during the reaction, depending on the type and/or the amount of water they are being mixed with. Not all hydrophilic polyurethane grouts expand during their initial reaction. The hydrophilic polyurethanes, especially in North America, often have been utilized to fill the gap in the market left by AM9, when production of this product was "officially" terminated (?) in 1978. There is, however, a serious problem with rapid deterioration and water absorption by the hydrophilic polyurethanes after reaction.

Water-reactive prepolymers are high molecular grouting materials. They are primarily produced by mixing a polyol with an excessive amount of poly-isocyanides to form a low prepolymeric compound, containing some free OCN groups. The injection resin is composed of this prepolymer, plasticizer, diluting agents, surfactants and the amine catalyst.

The mechanism of reaction among the isocyanides, polyol and other components is rather complicated. In simple terms the following happens:

1) The reaction between the isocyanides and the polyol yields a pre-polyurethane.
2) The reaction of poly-isocyanides with water liberates carbon dioxide and urea derivatives.
3) The reaction of poly-isocyanides with ureido develops molecular links and high molecular formation.

These reactions occur because of the existence of the free OCN groups in the grout, which can react with the compounds containing active hydrogen atoms, such as hydroxy, water, amino and ureido. The hydrogen atoms move to link up with the nitrogen atoms of the poly-isocyanides and form high molecular polymers.

Subcategory 1: Hydrophobic "semi-rigid" and "rigid" Hydrophobic Water Reactive Prepolymers: They are mainly used for blocking water inflows and soil grouting in the presence of moving ground water or when high strengths are required, when excellent chemical resistance is required in environmentally sensitive areas or when durability is an issue.

At the turn of the century there were approximately 20 manufacturers involved in the manufacturing of these grouts. The oldest products on the market were the TACSS series, manufactured by Takenaka in Japan. The DeNeef Company deserves credit for making polyurethane grouting popular in a great deal of countries.

These products react with the in-situ water and expand during the exothermic chemical reaction, releasing carbon dioxide. They are totally stable after reaction, but have limited flexibility. The reaction time can typically be adjusted between 45 seconds up to one hour by adding a tertiary amine-based catalyst.

Figure 1 illustrates a typical reaction curve for water reactive hydrophobic polyurethane prepolymers. First there is an induction time during which the viscosity of the water/P.U mix remains constant followed by the reaction time, during which the foaming starts. The latter is associated with a decrease in viscosity followed by a very rapid increase in viscosity prior to final gelation. The reaction pattern of hydrophobic polyurethanes displays a shotgun reaction pattern.

Heating the grout (max. 60°C - and never directly applying the heat to the grout-containers) speeds up the reaction. If shorter set times are required, a resident tube is used: water or cement-based suspension grout is injected via separate lines into a resident tube, in conjunction with the prepolymer as indicated in Figure 2. This way, the grout has already passed the "induction phase" of the chemical reaction, when introduced into the formation or the water-flow. By providing a grouting set-up, in which the "water introduction point", can be continually altered (mobile feeder-pipe through stuffing box connected to the resident tube), the resident time can be continually changed, and hence the reaction time. Grout wash-out can be eliminated under most circumstances.

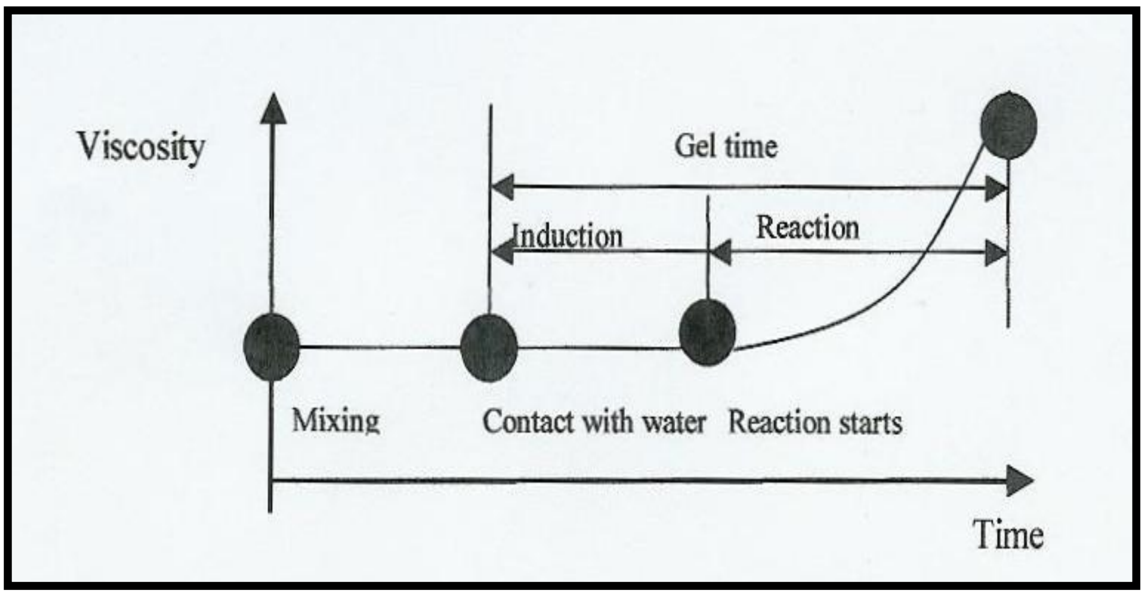

Figure 1. Typical reaction curve for
water reactive hydrophobic polyurethane

Prepolymers

The water cut-off series of prepolymers has been developed for stopping major inflows and seepage control. They are most suitable for the rather crude applications when water has to be stopped, but not necessarily "to the last drop". As a result, they are ideal trouble shooting products for stopping or controlling major inflows in geotechnical applications. Grouted soil or cured grout, has a residual permeability in the 10-4 to 10-6 cm/sec range, which will allow minor seepage to take place.

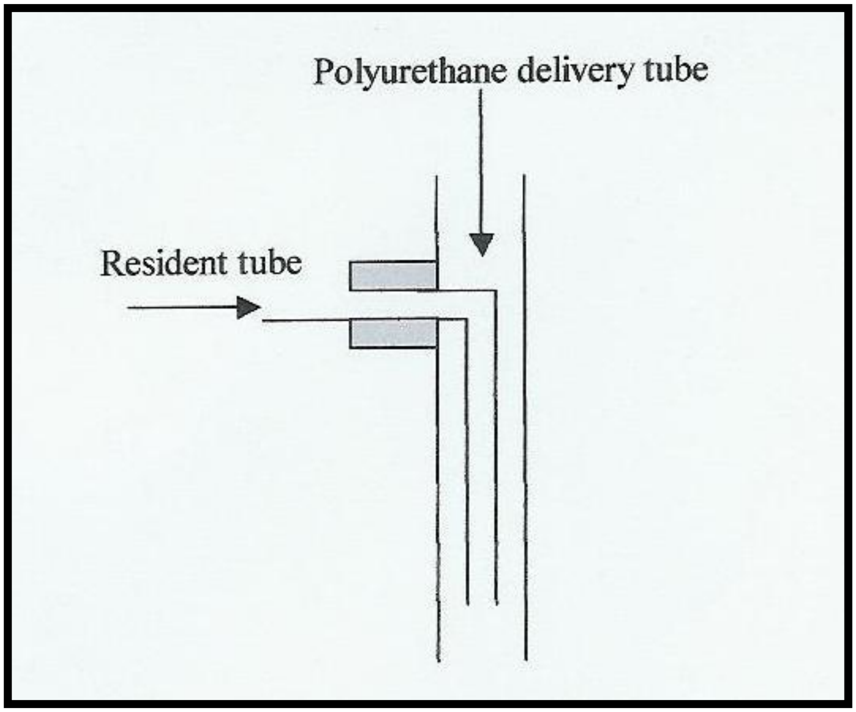

Figure 2. Resident tube

Products within the same family of hydrophobic polyurethane differ due to:

- viscosity
- miscibility with water
- purity of the MDI
- reactivity at elevated pressures
- toxicity (solvent content and type of isocyanides)
- cellular structure of the freely foamed cellular structure of the freely foamed PU
- residual hydraulic conductivity of grouted medium

Several manufacturers have obtained potable water approvals, for their water reactive hydrophobic polyurethane prepolymers.

In order to start the reaction, there is a minimum enthalpy required, which is higher, as the pressure is higher. This means that, at a given pressure, if the enthalpy is too low (temperature too low) the reaction does not start unless the products are mixed thoroughly with the water. Naudts (1986) established a reaction-diagram for some of the hydrophobic polyurethane grouts (Figure 3.)

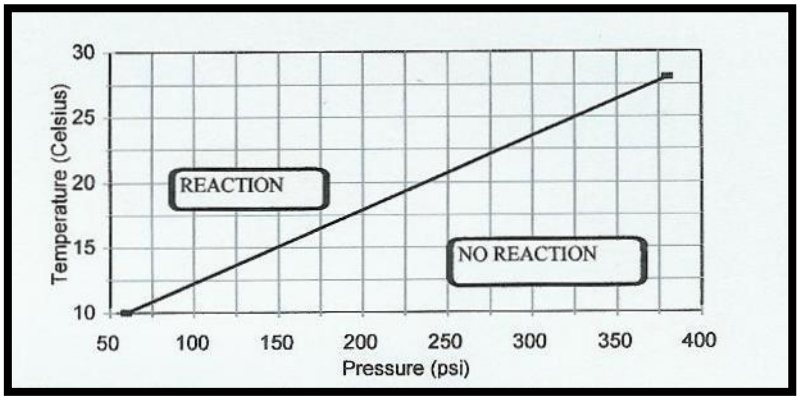

Figure 3. Water reactive prepolymer (for Tacss 20)

Above the "reaction" line the reaction takes place, and below this line reaction does not occur unless mechanical agitation of "in situ water" and the polyurethane grout is provided. The (turbulent) flow of the urethane-water mixture through cracks and channels often provides for enough in-situ mixing. Some of the more recently developed prepolymers react regardless of pressure and groundwater temperature.

During grouting, the carbon dioxide, generated during the chemical reaction, will generate additional pressure, as the grout flows through the cracks and pore channels, pushing the grout into very fine cracks and crevices. The reaction pressure in totally confined circumstances is over 2.5 MPa (350 psi) as was determined in the bomb test by Naudts (1986). Other researchers (Tjugum 1991; Burgstaller 1989) indicate lower values, mainly because polyurethane was given the chance to expand during their experiments, compressing small quantities of air in the test chamber. The formation is, in reality, never completely sealed and the expansion pressures are in the order of 0.5 to 1 MPa (70 -150 psi).

Where it is absolutely necessary to control the reaction times it can be achieved by injecting the prepolymer as a two component grout, with water or cement-based suspension grout being the second component, separately introduced into the manifold. By using the header-pipe as resident pipe, and selecting an induction period, a little longer than the resident time, it is possible to control an inflow. This is a fairly sensitive operation as the flow pattern in the structure to be sealed is continually changing during the grouting operation.

Only MDI-based prepolymers should be used. The vapour pressure (at ambient temperature) of the solvent free MDI based products is low. However, ventilation is still required when working in enclosed spaces in order not to exceed the maximum T.L.V. limits of 100 ppb (8 hour period), as determined by the International Institute for Isocyanides.

The long term durability of grouts has been researched via accelerated ageing tests. Credible work has been done by the Swedish National Testing Institute (Jakubowicz, 1992). Accelerated ageing tests by Naudts (1990) revealed that in highly acidic environments; polyurethane is anticipated not to break down more than 10% over a 100 year time period. In an alkalic environment (such as in concrete or in limestone formations), a weight loss of 35% has been projected over a 45 year period because of hydrolytic degradation of the cured polyurethane. Soils grouted with polyurethane, according to Takenaka (1976) and research work by Oshita, et al. (1991), do not display signs of long-term degradation.

Please note that even properly formulated cement-based suspension grouts do not perform nearly as well as water reactive polyurethane grouts in an accelerated ageing test, even under normal conditions.

The unconfined compressive strengths (UCS) of soils grouted with polyurethane prepolymers strongly vary from type to type. The rigid types produce a much higher strength than the semi-rigid types. Years ago, solvents were used to reduce the viscosity of the rigid polyurethanes to enhance penetrability; this is no longer acceptable for environmental reasons. The grain size distribution of the soil has also a significant impact on the UCS of the grouted soils. The grouting pressures also influence the UCS of the grouted soil and its residual permeability. The water content and the permeability coefficient of the soil play an important role too. In order to avoid unpleasant surprises, lab simulation injection tests such as the ISIS tests as described by Landry, et al. (2000), provides reliable results in predicting the injectability and the characteristics of the grouted soils.

Examples of Field Applications:

Soil Grouting: Containment of toxic spill in overburden after train derailment in Kinkempois (Belgium) 1990.

In order to prevent toxic chemicals from flowing into the river a grout curtain was installed within hours after the spill occurred due to a train derailment. Steel sleeve pipes were installed at close spacing through the silty sand overburden overlaying the bedrock. It is important to use sleeve pipes of good quality to prevent backflush through the sleeves. A fast curing, chemical resistant, rigid water reactive polyurethane was selected for this project.

Rock Grouting: Sugai Piah Hydroelectric Project (Malaysia) 1993.

A grout curtain through fractured granodiorite and a gouge filled fault zone was installed under flow conditions (20 litres/second) and high pressure (1- 3 MPa). Water reactive polyurethane was injected in conjunction with cement-based grout to form a grout curtain with a residual permeability of less than 0.1 Lugeon. The grout curtain extended radially 20 meters around a concrete plug, near the bottom of a drop shaft.

Multiple hole grouting via multiple port sleeve pipes using secondary and tertiary and quaternary grout holes were utilized. Balanced, stable cement-based grouts were used in upstream holes at the same time as the polyurethane grouts were injected in the downstream holes. The permeability of the formation was systematically reduced from over 300 Lugeon to less than 0.1 Lugeon without suffering washout of grout.

Sealing soil piping conditions through joints in deep tunnels, and coffer dams below the water-table

Most subways in Western Europe consist of multiple level tunnels, as deep as 30 metres (100') below the groundwater table in fine granular soils. Failures in joints have devastating consequences.

Failure in joint between slurry-wall panels near the "Midi Tower" in Brussels (Central station) - 1982.

Several tunnels in the Brussels Subway were constructed using the slurry wall system. During the excavation of the second underground level, a leaking joint suddenly gave away during the night, causing a major inflow of water and fine sand into the tunnel. A massive sinkhole was formed at the Midi Square immediately beside a 45 story building. Bentonite inclusions formed in the joints between panels of the slurry walls suddenly blew out.

Soil drifting into the tunnel disturbed a large area, endangering the foundation system of the Midi-Tower. Within hours an emergency grouting program was launched. It involved prepolymer drenched pads and wedges blocking the soil-inflow, within the hour. The water inflow was stopped within eight hours via horizontal sleeve pipes installed near the failed joint. A soil grouting program (using vertical sleeve-pipes) involved cement based suspension grouts, sodium silicates and polyurethane prepolymers, to create a soil conglomerate on the outside of the joint, to full depth, successfully protecting the tunnel joint against future failures, and allowing a safe structural rehabilitation program from inside the tunnel.

Pre-excavation grouting to control or prevent inflows in rock-tunnels and shafts

Francoeur Mine Shaft sinking, Val D'or, Quebec.

In spite of systematically drilling pilot holes, a steeply dipping, water bearing fault zone went undiscovered during a shaft sinking operation at the Francoeur Mine. After blasting a round, a major in-rush of water occurred on one side of the shaft under high pressure (4.5 MPa (630psi)). An emergency bulkhead was created at the bottom of the shaft to channel the flow through relief pipes. Hydrophobic polyurethane in conjunction with stable cement based suspension grout was injected to stop the inflow. The water-bearing feature was systematically grouted with a combination of polyurethane and cement grouts. This approach made it possible to blast within one hour after completing a grouting operation. The shaft sinking was only interrupted for 5 days. This system has been used numerous times to eliminate down-time when driving tunnels through unstable water bearing rock formations.

Tunnel Grouting in Hardrock Tunnels: Emergency situations

In 1987, during the installation of a deep tunnel in Geneva (Switzerland) for CERN (Centre European de Recherche Nucleaire), major infiltration problems were encountered. The 27 km long rock tunnel is located 160 m below the water-table. The tunnel was excavated with a four meter diameter WIRT TBM. At one point, a chalk horizon with interbedded clay seams was intersected. The clay extruded from the seams resulting in a major inflow. A cement grouting program was launched. After injecting 600 metric tons of neat cement grout and cement with sodium silicate in combination, interrupting tunnelling operations for more than 60 days, no reduction in inflow was measurable. The total inflow (aquifer limited) remained steady at 400 litres/second (6,300 gpm). A decision was made to proceed with water reactive hydrophobic polyurethane prepolymers. The total inflow was reduced to 37 litres/second in only two days of grouting to meet design criteria.

Dam and dike grouting to prevent seepage through the abutment or the embankment

An extensive rock grouting program was performed in Montezic (French Alps) in the Digue de Monnes (owned by EDF) in 1988 to stop further leaching of an old grout curtain made using sodium silicates and cementitious grouts. A sleeve pipe grouting program was launched, to restore the integrity of the old dam. The casing grout, surrounding the sleeve pipes clogged some of the minor fractures, which reduced access of the grout to the formation. It is poor grouting practice to use casing grout around sleeve pipes for rock-grouting. Towel packers (or MPSP barriers) would have been much more appropriate (in lieu of the sleeve pipes) to create a grout curtain along the centre-line of the dike. Rock hydro-fracturing was required to access and grout the open cracks (with flowing water) and to eliminate seepage through this dike. The set time of the water reactive grout was selected at 75% of the flow through time.

Renovation of Man-Accessible Sewers

This is one of the most common applications for this type of water reactive prepolymer. One of the first rehabilitation projects on man-accessible sewers subject to internal erosion (even soil piping conditions) occurred in Mechelen (Belgium) in 1977. The technique, now applied all over the world, only slowly found its way to North America. One of the first jobs of this kind in North America has been executed at
Niagara Falls (Canada).

Sewer Rehabilitation on Dorchester Road, Niagara Falls, Ontario. (1988/89)

During 1988 and 1989 the pavement of this very busy road collapsed a few times causing some spectacular accidents (vehicles driving into substantial sink holes. A 25-year-old sewer, located at a depth of about 7 metres below the pavement appeared to be the cause of the problem.

Loss of fine soil particles through leaking joints triggered an "internal erosion process" which in turn created voids above the watertable, eventually turning into sinkholes. Remedial measures that were undertaken consisted of the following:

- Installation of a proper ventilation system in the sewer-line
- Installation of bulkheads and pumping the incoming sewage to the next manhole
- Cleaning of the section to be repaired
- Drilling of at least four injection packers in each joint as pressure relief holes and sealing the zone between the packers with hydraulic cement or with pads drenched in prepolymer
- Grouting of the joints (from packer to packer) with a water reactive prepolymer until the grout travels through the entire joint sealing it completely
- Installation of sleeve-pipes (anchored in place, using prepolymer collar pads) from the inside of the sewer-line followed by a cement suspension grouting program, embedding the sewer-line in cement based suspension grout and providing the required lateral uniform support to the sewer line to prevent ovalisation and cracking

More than 1.5 km of sewer grouting has been carried out in Niagara Falls since September 1989, successfully rehabilitating the old sewer for a fraction of the cost building a new sewer.

Subcategory 2: Hydrophobic Water Reactive Polyurethane Grout:
Hydrophobic "Flexible" Prepolymers: These products remain flexible over time and do not undergo volume changes after curing. The foam contains a certain percentage of open cells, when curing under atmospheric pressure. As a result, grout has to cure under pressure to form an effective elastic seal.

Flexible prepolymers should only be used for joint and crack-injection and seepage control, but not for soil grouting. The high viscosity of the prepolymer is an advantage when inflows have to be sealed through wider apertures. The high viscosity increases the resident time of the prepolymer in the formation. Flexible hydrophobic prepolymers are less reactive than most other water reactive prepolymers.

Sault Ste. Marie Locks Rehabilitation. Michigan, U.S.A.

The U.S. Army corps of Engineers (USACE) Sault Ste. Marie Division embarked on a substantial crack injection program to stop the seepage after specialist contractors had only limited success. The USACE executed the work with in-house staff that were trained by outside consultants in proper crack injection techniques: angled drilling towards the mid-point of the cracks; acid flushing with phosphoric acid; and multiple hole grouting until grout travels to adjacent packers.

It is noteworthy that a crew without any previous experience in grouting successfully and permanently sealed more than 10000 lineal feet of damp and badly leaking cracks, regardless of the brand of flexible prepolymer used. It was confirmed that the travel times through fine cracks, as derived from the mathematical model based on Anderson's research work (Anderson in 1998), was predictable. It takes more than 15 minutes for polyurethane to travel 1 meter through a crack of 20 micron under a pressure of 500 kpa (70psi). USACE staff experimented with the use of acid flushing and treated several sections without acid flushing. These tests revealed irrefutable evidence that acid flushing is mandatory for permanent sealing of cracks.

Hydrophilic Water Reactive Polyurethane Grouts

These products are grouted in conjunction with water and form a hydrophilic gel or a hydrophilic foam (depending on type and mixing ratio). They are often more efficient than the hydrophobic prepolymers, to stop major inflows, because they are more reactive (i.e. they react much faster and the duration of the reaction is much shorter).

Hydrophilic gels appear not to be stable in time. The rate of deterioration differs from product to product. The cured gels tend to physically absorb water, thereby increasing their porosity, losing their bond and some or all of their waterproofing and mechanical characteristics. Some products do not survive accelerated aging tests. Since these products absorb water after gelation, they exert a swell pressure that sometimes cannot be sustained by the structure, resulting in structural damage.

Utmost care is recommended when selecting these products for an application. When the products are mechanically confined, the post-swelling is rather a positive characteristic since a tighter "gasket" is created. It is the author’s experience however, that these products are questionable for long-term solutions.

Polyurethane Elastomers (2 Component Grouts)

These products consist of 2 components: the polyol (usually a poly-ether polyol) on which a catalyst is added to select the gel time; and, the isocyanate: preferably an M.D.I. (Diphenylmethanediisocyanate) type, since T.D.I. (Toluene Diisocyanate) types pose severe health hazards at ambient temperatures.

The first generation of polyurethane elastomers has been used in Germany since the early sixties under the name "polytixon". The polytixon products are T.D.I. based; oils were used to lower the viscosity, and to dilute the polyol.

Since 1984, a new generation of polyurethane elastomers has been introduced to the grouting industry resulting in a considerable improvement to the rehabilitation and seepage control grouting.

In cured form these grouts are totally inert and hydrophobic, and most of the above products remain flexible in time, even at low temperatures. These products have an excellent penetrability in cracks and are more suitable than the classic epoxy grouts for structural repair work in concrete, because of their flexibility. An engineered approach towards continuous monitoring methods of cracks has been long overdue. Wiechmann (1990) developed a continuous monitoring device which allows to evaluate movements of joints and cracks, pinpoint the cause and determine in a meaningful and engineered fashion the appropriate remedial measures (methodology and product selection).

The tensile strength and the bond of the urethane must exceed the tensile strength of the concrete, to be suitable to seal active cracks in concrete structures. It is our experience that cracks and joints fluctuating more than 40% in width are very difficult to seal, unless a "cap" on the upstream side of the joint or crack can be created.

Applications of Hydrophobic Urethane Elastomer

Sealing cracks and joints in concrete and masonry.

Whenever practically possible, polyurethane elastomers should go selected over water reactive polyurethanes. The appropriate type has to be selected for the application at hand.

Injectable tube applications (contact grouting)

Grouting, via pre-placed injectable tubes, is gradually becoming an integral part of the design to create water-tight construction joints, or to "glue" old concrete to new concrete, or as an alternative to water-stops.

Air and water leaks often occur through cold joints in structures. To prevent these types of problems, injectable tubes were invented in Germany in 1982 and are now used world-wide. This is one of the most genuine applications where grouting is used as a construction tool, rather than as a remedial measure.

P.U. Elastomers Subcategory 1: Water Compatible Hydrophobic Elastomers

These products displace water in cracks and cure without foaming or reacting with the water, to form an hydrophobic elastomer, with acceptable adhesion to the medium. The elastomer is not affected by wet/dry cycles and is stable in time. These products are suitable for grouting into water-bearing formations, cracks or joints (not running), and for grouting into injectable tubes filled with water to create an elastic "gasket" between two members. They are also very suitable for repair work of wet cracks in concrete structures.

Pedestrian Tunnel Rehabilitation, Ottawa, Canada, 1989.

Persistent seepage had been a serious nuisance in the pedestrian tunnel between the central block and west block on Parliament Hill in Ottawa. Water bypassed several waterproofing membranes (copper, rubber) and entered the tunnel via the expansion joints. During the rehabilitation program, carried out in December 1989, a water repellant, two-component polyurethane grout was injected, forcing the water out of the joint and resulting in a flexible completely inert two-component polyurethane elastomer.

P.U. Elastomers: Subcategory 2: Hydrophilic Polyurethane Elastomers

These grouts swell out after they have cured in contact with water. They are predominantly used for crack-injection in dry or damp joints or for use in injectable tubes. Once cured, they swell out in a predictable way when in contact with water, to form a tight gasket.

The major difference with the pure one component hydrophillic prepolymers is that the elastomers have a hydrophobic matrix, with "active antennas", attracting water. The percentage of swelling is predictable. These elastomers do not lose their mechanical characteristics, because of their hydrophobic matrix. Typical applications include: pickotage ring in shafts; sealing around flood bulkheads; prefabrication of "swell-seals" of any size or dimension for joint sealing or prefab applications; injectable tube grouting (tunnels, parkades, swimming pools, etc.); and cast-in-place expansion joints.

Fjellinjen Tunnel in Oslo (Norway)

In the design of this tunnel the installation of injectable tubes in every cold, construction and expansion joint was specified. The injectable tubes were all grouted, after the structure had settled, with a two component polyurethane elastomer, Polycast EXP. This grout cures to form an elastic rubber. When water penetrates the joint, the grout swells out to a maximum pre-determined amount. Similar applications took place in the Liefkenshoektunnel (Antwerp Belgium 1990) and the Piet Heyn tunnel (The Netherlands 1993).

Hydroblock

This is a two-component auxiliary grout (cement-urethane) grout developed by Verstraeten in the late 1980's. A-component consists of a partly cementitious based suspension grout, on which a particular type of amine has been added. The B-component consists of a cocktail of polyol. The mixing ratio (A/B) is approximately 10-15/1. Both products are injected via concentric pipes, whereby the B component is only introduced at the exit point of the grout-line. No static mixer is required. The reaction time (in spite of the water flow) of the grout is less than a second. The cement grout gels instantly, forming spaghetti-like stringers, clogging up the seepage paths. The "soft grout spaghetti" continues to cure like a regular cement-based suspension grout, providing a permanent cut-off.

Two-component Polyurethane Foam Grouts

The result of the reaction between a polyol (R-OH) and an isocyanate (R1-NCO) is the creation of a polyurethane. Depending on the type of polyol, blowing agents, catalysts, a wide variety of foams with different characteristics can be formed, only differing in: density, cellular structure, compressive strength, reaction pattern (cream time - tack free time), water absorption, fire resistance.

The isocyanate has a high affinity for water and thus has a tendency to "steal" the isocyanate, leaving not enough isocyanate for the polyol to form a complete reaction. Typical applications include: stabilization of unstable rock in mines; sealing previous formations in front of flood bulkheads; sealing gaps and joints around ventilation doors; filling damaged "air-caissons" (locks); and, pipeline applications such as temporary floating blocks for river crossing, and erosion cushions).

Conclusions

Although polyurethane grouts have been extensively used worldwide for almost four decades, some large grouting firms still have not caught on to this trend. Polyurethane grouts provide solutions to problem situations especially when major inflows are present or when long term performance is required. Although more durable than cement-based grouts, the water reactive hydrophobic polyurethane grouts do not last for ever in highly alkaline environments but are very durably in neutral and acidic environments. Sound research work has been performed confirming what practitioners experienced pertaining to penetrability of polyurethane grouts in cracks: acid flushing and multiple hole grouting are absolutely necessary prior to grouting cracks in concrete and is advantageous when grouting limestone formations.

With increased awareness of environmental matters, most polyurethanes offer a solution of grouting in potable water environments. It is important to be aware that most hydrophilic, water reactive polyurethanes continue to absorb water while degrading. Two component polyurethane foams have branched out from their classic applications in mining to geotechnical applications.

Understanding the characteristics of the large variety of polyurethanes is necessary for proper product selection. Most of the research work on polyurethane grouts has been performed in Scandinavia. There is still more to be learned about this fascinating family of products that democratized the grouting industry.

References

Andersen, H. (1998) *Chemical Rock Grouting. An experimental study on polyurethane Foams.* Chalmers University of Technology, Goteborg. S-41296.

Burgstaller, C. (1989) *Numerische Simulation von Schauminjetionen auf der Basis von experimentellen Untersuchungen*. Nontan Universitat Leoben, Germany.
Hepburn, C. (1992) *Polyurethane elastomers*. Elsevier Applied Science. London, New York.

Jakubowicz, I. *Determination of Long Term Properties for Polymer Based Grouts* conference proceedings. Nordiskt Symposium I berg injektering. Ed. Lundblom Chalmers University of Technology, Goteborg. pp 50 . 56.

Landry, E, Lees, D, and Naudts A. (2000): "New Developments in Rock and Soil Grouting: Design and Evaluation." *Geotechnical News*. September 2000. pp 38-44.

Naudts, A. (1986). "Research & lab testing program on the use of acrylamide and polyurethane grouts under high pressure." IMC. Esterhazy. Unpublished.

Naudts, A. (1990) "Research Project Fort Cady Minerals: Chemical resistance of modified cement-based grout and polyurethane grouts Accelerated ageing test." Unpublished.

Naudts A., (1994) "Soil Grouting to Improve Foundation Soils." *Practical Foundation Engineering Handbook*. ed. R.W. Wade. McGraw Hill. pp 5.340 . 5.363

Oshita, T., Kitano, M., and Terashima, K. (1991) "Long Term Durability of Sails Solidified with Hydrophobic Polyisocyanate type grout." *Society of Materials Science*. Japan. December. pp. 1552 . 1557

Takenaka. (1976) Tacss know-how books. Internal Publication

Tjugum A (1991). *Utrikling av testnetade for injeksjonsmidler I beveglige riss*. Norwegian Institute of Technology. Trondheim

Verstraeten, P. personal communications

Weichmann, M. (1990) "The need for continuous monitoring by accurate instrumentation in analyzing structural movements." Second International Grouting Conference in Canada, Toronto.