

INSTRUMENTS AND METHODS

HIGH PRESSURE COUPLING FOR PIPE IN DEEP WATER-FILLED BORE HOLES*

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ABSTRACT. In August 1961 an aluminum pipe (3.5 cm. internal diameter, 4.2 cm. external diameter) having 92 specially modified socket couplings (5.0 cm. external diameter) sealed with a quick-polymerizing synthetic rubber was sunk 226 m. in a vertical water-filled bore hole in Blue Glacier, Washington, U.S.A. The geometry of threads and mating surfaces of pipe and coupling was designed to cause increasing external water pressure to tighten the seal. One joint at a depth of 66 m. immediately developed an extremely slow leak (probably because of faulty cleaning), but the other 91 joints apparently were sound, as the pipe was free of water to a depth of at least 157 m. when resurveyed after one year.

RÉSUMÉ. En août 1961 un tube en aluminium (diamètre interne 3,5 cm, diamètre externe 4,2 cm) a été enfoncé de 226 m dans un trou de forage vertical rempli d'eau, dans le Blue Glacier, Washington, U.S.A. Ce tube possédait 92 manchons d'assemblage (diamètre externe 5 cm) spécialement modifiés; la géométrie des filetages et des surfaces d'assemblage a été étudiée de façon à ce que les joints soient rendus étanches par la pression extérieure de l'eau. Une faible fuite s'est immédiatement développée dans le joint à la profondeur de 66 m (probablement par suite d'un nettoyage défectueux) mais les autres 91 joints étaient apparemment étanches puisqu'une observation réalisée un an après a montré que le tube ne contenait pas d'eau jusqu'à une profondeur d'au moins 157 m.

ZUSAMMENFASSUNG. Im August 1961 wurde ein Aluminium-Rohr (innerer Durchmesser 3,5 cm; äusserer Durchmesser 4,2 cm) 226 m tief in ein senkrecht, wassergefülltes Bohrloch im Blue Glacier, Washington, U.S.A., eingelassen; das Rohr hat 92 Verbindungsmuffen (äusserer Durchmesser 5,0 cm), die besonders zugerichtet und mit einem schnell polymerisierenden synthetischen Gummi abgedichtet wurden. Die Gewinde und Stirnflächen waren so gestaltet, dass äusserer Wasserdruck die Abdichtung noch verstärken musste. Eine Muffe in 66 m Tiefe zeigte sofort ein ausserordentlich schwaches Leck (vermutlich wegen unzureichender Reinigung), aber die übrigen 91 Muffen waren offensichtlich dicht, da das Rohr bei der Nachprüfung nach einem Jahr mindestens bis zu einer Tiefe von 157 m wasserleer war.

INTRODUCTION

A principal method of investigating the flow field within a glacier is to place a pipe in a deep nearly vertical bore hole and periodically measure its deformation by inclinometer surveys. In a temperate glacier, which is at the melting temperature throughout, except for a superficial layer transiently chilled by winter cold, a pipe in a bore hole is almost invariably immersed in water, in which the pressure increases about $0.1 \text{ kg.wt. cm.}^{-2}$ for each meter of depth. Contrary to the normal situation, this pressure is applied to the outside rather than the inside of the pipe. The majority of bore-hole experiments on temperate glaciers have shown that ordinary pipe threads and jointing compounds tend to leak when the depth exceeds about 100 m., corresponding to an external pressure greater than $10 \text{ kg.wt. cm.}^{-2}$.

We have verified this tendency in the laboratory by testing, in a pressure vessel, several variants of the common socket pipe coupling in combination with a variety of commercial pipe jointing compounds. The tests were conducted on aluminum pipe and couplings having a nominal size of $1\frac{1}{4}$ in. (3.5 cm. internal diameter, described in the next section) with three combinations of threads (tapered external with tapered internal, tapered external with straight internal, and straight external with straight internal). Experiments were also carried out with a coupling machined so that its wall thickness tapered from normal at the center to almost a feather edge at the ends (both external and internal threads tapered). Jointing compounds tried were either non-hardening lubricants (essentially grease with various additives, such as graphite or molybdenum sulfide) or hardening sealants (all of which hardened by evaporation of a solvent). Thiokol rubber compound (described in the next section) or similar sealants unfortunately were not available at the time of these experiments.

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Water inside a bore-hole pipe is undesirable for a number of reasons. The most important is that, even in temperate glaciers, water that leaks into the pipe usually freezes, oftentimes even at great depths, thereby preventing passage of surveying instruments. Fuller details on this will be included in a paper on bore-hole operations and observations on Blue Glacier, Mount Olympus, Washington, by R. L. Shreve and R. P. Sharp. Another reason is that water slows the passage of such instruments through the pipe, as well as making it necessary that they be hermetically sealed. Finally, a water-filled pipe, being non-buoyant, exerts considerable pressure on the walls and bottom of the bore hole.

On the other hand, water inside a bore-hole pipe has certain advantages. Because of the greater weight concentrated near the bottom, thermal drilling with the drill pipe filled with water results in greater hotpoint efficiency (Shreve, 1962, p. 157-58), hence greater drilling speed and a narrower, straighter hole. Also, the water buoys and lubricates heavy cables inside the pipe, such as hotpoint power cables or instrument control cables, thereby making them easier to lift and tending to keep them from tangling or jamming.

Even if a pipe is filled with antifreeze rather than water, pressure-tight seals at joints are necessary to prevent the antifreeze from escaping when the water level in the surrounding ice drops, as it often does at night and, to a far greater extent, in winter. In this case the sealing problem is not so difficult because the higher pressure is on the inside; but, as long periods of time are involved, even very tiny leaks are intolerable. Bore-hole pipes in temperate glaciers must therefore be made pressure-tight whether they are filled with antifreeze or maintained dry.

DESIGN

In addition to being pressure-tight, couplings for glacier bore-hole pipes should be simple and inexpensive, should be easy to assemble in the field under adverse conditions of weather and illumination, should present a smooth unbroken interior surface, should not deteriorate with time or exposure, and should be capable of disassembly and reassembly in the field.

A pipe joint designed for these requirements is shown in longitudinal cross section in Figure 1. Additional, fixed requirements in this case were that $1\frac{1}{4}$ -inch American Standard Schedule 40 aluminum pipe (3.5 cm. internal diameter, 4.2 cm. external diameter) had to be used and that joints could not exceed 5.0 cm. in diameter. Because of the small space available, therefore, neither O-ring seals nor separate packing utilizing the unsupported-area principle

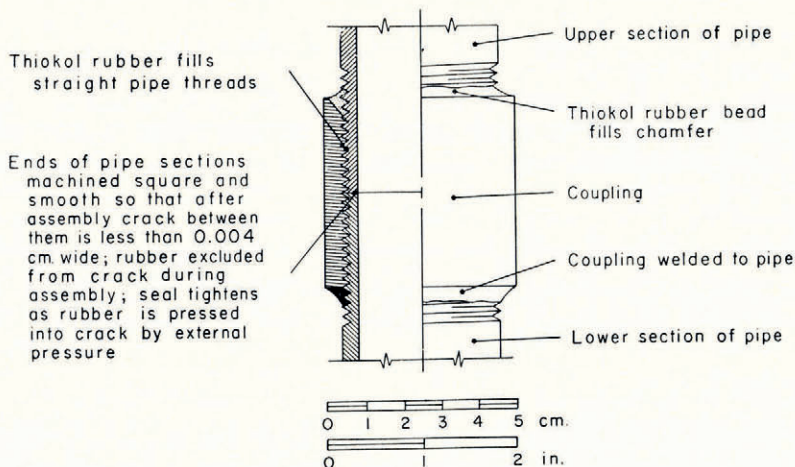


Fig. 1. Longitudinal cross-section of pipe coupling with cast rubber seal

(Bridgman, 1914, p. 627-629, 636, 639), which are ordinarily used with high pressure fluids, could be employed. The principle of the O-ring seal is utilized, however, in that a flexible, elastic sealant is cast in the joint in such a way that increasing external pressure tightens the seal.

Specially formulated thiokol rubber was used as sealant. It comes as a viscous, sticky "base" which is thoroughly mixed with a measured proportion of "accelerator" to cause polymerization. Exposure to air or heat is unnecessary. The unpolymerized compound flows easily, does not pull apart, and serves as thread lubricant during assembly. At 0° C. a strong, flexible, elastic, nonporous rubber forms about 10 min. after mixing. The speed of polymerization can be increased by increasing the proportion of accelerator or the temperature, but too much accelerator, too high a temperature, or poor mixing results in a spongy, somewhat weaker product.

The rubber bonds strongly to aluminum, but the surface to be bonded must be completely free of dirt, oil, and water. This means that just before assembly the threads of every joint must be meticulously cleaned with acetone and that thereafter no water or oil whatever must get on them. Precleaning the pipes and couplings with high pressure steam and coating the joints with oil-free protective plastic before shipment to the glacier greatly facilitates the cleaning process.

PERFORMANCE

In August 1961 a vertical, water-filled bore hole 226 m. deep was thermally drilled in Blue Glacier, Mount Olympus, Washington, U.S.A. (bore hole B), and in it was sunk a pipe having 92 joints of the type shown in Figure 1. The intention was for the pipe to remain free of water, but unfortunately one slow leak developed immediately at a depth of 66 m., the other 91 joints apparently being sound. This leak probably was due to faulty cleaning of one joint. Cleaning was particularly difficult because the joints had not been precleaned and had inadvertently been coated with an oil-saturated protective plastic.

In August 1962 this pipe was resurveyed and found to be blocked at 66 m., the depth of the leak discovered the previous year. No water, however, was standing in the pipe even at this depth. A small diameter hotpoint lowered into the pipe quickly penetrated about a meter, at which point it fell free. This behavior implies that the obstruction consisted of a coating of ice more than 0.25 cm. thick for the first meter and less than 0.25 cm. thick for an unknown distance beyond, probably no more than a few meters.

The survey was resumed and no water was encountered to a depth of 157 m., at which point a second obstruction, not present in 1961, was found. The hotpoint was again lowered, but it burned out after about a minute. This behavior indicates that the obstruction was not due to ice and confirms that no water was standing in the pipe at this depth, which in turn eliminates a leaking seal or a broken coupling as the cause of the obstruction. Unfortunately, the two wires (No. 8 American Wire Gauge 7-strand single copper conductor with 0.1 cm. plastic insulation, external diameter 0.635 cm.) used to supply power to the hotpoint became jammed in the pipe, preventing their withdrawal, even after filling the pipe with ethylene glycol antifreeze and water and applying up to 200 kg.wt. tension; therefore, whether the obstruction was due to a sharp bend in the pipe or to rubber sealant extruded into the pipe remains undetermined.

DISCUSSION

Pipe joints, such as the common pipe coupling in which threads are cut in the ends of the pipe, are mechanically weak, particularly when bending is involved. In bore holes on Blue Glacier failures of pipe joints on account of bending occur most frequently during the first year of deformation, mostly at depths great enough that the rate of bending exceeds

about $0.5 \text{ deg. m.}^{-1} \text{ yr.}^{-1}$. It is therefore somewhat surprising that the obstruction at 157 m. in the 1961 bore hole on Blue Glacier was apparently not due to a broken pipe joint. In order to increase the strength of the joints of pipes sunk in Austerdalsbreen, Norway, Ward (1961, p. 533) welded external sleeves to the ends of each section of pipe and threaded them rather than the pipe. He also used finer threads and longer, heavier couplings than usual.

Pipe with couplings of the type described in this paper costs about 50 per cent more than the same pipe with ordinary couplings. The added cost is due primarily to the three machining operations involved in making the chamfer on the coupling, and the threads and facing on the two ends of pipe to be joined. On the basis of our experience some of the more conservative elements of the design could be modified, resulting in considerable reduction in expense with no significant loss in effectiveness. First, the chamfer in the coupling could be eliminated, as a sufficient rubber bead can be retained in the angle between the outside of the pipe and the square end of the coupling. Secondly, although they will have greater clearance than machined threads, die-cut threads could be used, although harder to clean and more likely to break. Finally, it may be that the thiokol rubber, or a similar material, would seal ordinary tapered pipe threads against high external water pressure; however, such a seal would not be of the O-ring type, hence its effectiveness would depend entirely upon the strength of the rubber and of the bond to the aluminum.

Welding the coupling to the pipe (aluminum alloy 6061-T6, Heliarc welding, two passes, no heat treatment) is worthwhile in any case because it is relatively inexpensive, it strengthens the joint, and, most important, it diminishes by half the number of potential leaks. Care must be taken, however, not to raise welts on the inside of the pipe that might impede the passage of close-fitting instruments.

To sum up, we feel that, despite the cost and only partial success of our experiment with cast rubber seals for pipe couplings, they are so simple and effective, and have such potential for improvement, that they definitely merit further experimentation and development.

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REFERENCES

- Bridgman, P. W. 1914. The technique of high pressure experimenting. *Proceedings of the American Academy of Arts and Sciences*, Vol. 49, No. 11, p. 627-43.
- Shreve, R. L. 1962. Theory of performance of isothermal solid-nose hotpoints boring in temperate ice. *Journal of Glaciology*, Vol. 4, No. 32, p. 151-60.
- Ward, W. H. 1961. Experiences with electro-thermal ice drills on Austerdalsbreen, 1956-59. *Union Géodésique et Géophysique Internationale. Association Internationale d'Hydrologie Scientifique. Assemblée générale de Helsinki, 25-7-6-8 1960. Commission des Neiges et Glaces*, p. 532-42.