Polymer support fluids: use and misuse of innovative fluids in geotechnical works

Les polymères: l'utilisation de nouveaux fluides de forage en travaux géotechnique

Jefferis S.A.
Environmental Geotechnics Ltd. and University of Oxford, United Kingdom

Lam C.
The University of Manchester, United Kingdom

ABSTRACT: Bentonite slurries have been used for over sixty years for the temporary support of excavations such as bored piles and diaphragm walls. At intervals over this time polymer products have been tried in place of bentonite but not always successfully. Recently it has become clear that, if used properly, polymer fluids offer many advantages over their bentonite counterparts, including improved foundation performance, lower environmental impacts, smaller site footprint and also simpler preparation, mixing and final disposal as they are used at much lower concentrations. They are also more easily managed than bentonite. However, successful use requires that the some specific characteristics of polymers are respected, in particular, it must be recognised that they are sorbed onto soils so that the polymer concentration in solution drops during use.

RÉSUMÉ: Les coulis de bentonite ont été utilisés depuis plus de soixante ans pour la mise en œuvre des pieux forés et parois moulées. Des boues polymères ont été testées pour remplacer ces suspensions d'argile mais les résultats n'ont pas toujours été conclusifs. Récemment, il est devenu évident que, si utilises correctement, les polymères offrent de nombreux avantages, entre autre une amélioration de la performance de fondation et une réduction de l'impact sur l'environnement; les procédés de préparation et de mélange sont facilités ainsi que la disposition de déchets car la quantité de polymères utilisée est plus petite que la quantité de bentonite nécessaire dans les coulis de bentonite. Cependant le succès de l'utilisation des polymères est limité par certaines de leurs propriétés – en particulier, le fait qu'ils s'adsorbent aux sols diminue leur efficacité durant le forage.

KEYWORDS: bentonite, diaphragm walls, piles, polymer, support fluids.

1 INTRODUCTION

1.1 *Background*

Bentonite slurries have been used for over sixty years for the temporary support of excavations for slurry trench cut-offs, bored piles and structural diaphragm walls and somewhat more recently for slurry tunnelling. At intervals over this time polymer alternatives have been tried but not always successfully, so that for some the word 'polymer' has become an anathema. However, recent developments have shown that, if used properly, polymer fluids offer many advantages over their bentonite counterparts, including improved foundation performance, smaller site footprint, reduced environmental impact and simpler mixing and final disposal as they are used at much lower concentrations than bentonite.

The many advantages polymer solutions offer can be achieved only if specifiers and users have a proper understanding of their properties and their in-situ behaviour and recognise that not all polymers are the same – the properties of the various polymers used in excavation works can vary very substantially. Unfortunately, it is still not unusual for users and/or specifiers to treat excavation support polymers as if they were a single material similar to bentonite. Polymer solutions are fundamentally different fluids to bentonite slurries and each type of polymer has distinct physical and chemical properties which must be respected to avoid misuse.

1.2 *Natural and synthetic polymers*

Early polymer fluids tended to be based on naturally derived products such as carboxymethyl cellulose, xanthan and guar gums but they had a limited range of properties, were easily biodegraded and thus short-lived unless treated with biocides which can have negative environmental impacts. Furthermore, like bentonite they could not inhibit the dispersion of fine soils such as clays into the excavation fluid and thus required cleaning before re-use.

In recent years, the advent of synthetic polymers has allowed the development of fluid systems with tailored properties. Systems can be designed to be bio-stable, environmentally benign and to inhibit clay dispersion so enabling repeated use without specialised soil-slurry separation plant such as hydrocyclones, dewatering screens and centrifuges. Today, with these benefits, synthetic polymers account for the vast majority of polymers used for foundation construction and in oil-well drilling (where bentonite free muds are regularly used). Natural polymers continue to be used for excavation projects where rapid biodegradation is useful such as the construction of permeable reactive barriers and deep drainage walls.

1.3 *Objectives*

To promote best practice in the use of polymer support fluids for the construction of deep foundations, this paper sets out the latest understanding of the behaviour of polymer fluids and also presents experience drawn from recent research and case histories from around the world.

2 SUCCESS THROUGH PROPER USE OF POLYMERS

2.1 *Operational benefits*

The operational benefits offered by polymer fluids traditionally have been one of the main reasons for contractors to switch from bentonite to polymers. For example, Lennon et al. (2006) note that the size and cost of the ancillary plant required for bentonite slurries make them relatively uneconomic for urban sites with restricted space and access such as those in city centres. Figure 1 shows such a site in central Glasgow, UK which although measuring just 24 m by 40 m required sixty-two 750 mm diameter bored piles, i.e., approximately one pile every 4 m. The size of the site and the scope of the work meant that polymer fluids were the only feasible option because they do not require multiple holding tanks for slurry hydration nor do they require separation plant to recover the used slurry. Unlike bentonite slurries, polymer fluids require only a short swelling and hydration time prior to use and indeed emulsion polymers develop their properties almost instantaneously after mixing. Powered polymers, after wetting out, for example, with a Venturi eductor can be hydrated in an open-top tank gently agitated with a compressed air lance.

Figure 1. The small site in Glasgow where a polymer fluid was used.

Anonymous (2001) note that during the construction of the Channel Tunnel Rail Link (CTRL) East Kent-Ashford to Cheriton section, polymers were chosen because setting up a bentonite plant on some of the sites would have been almost impossible due to space restrictions. The saving of time for site set-up is an associated advantage. Compact polymer plant can be moved from site to site relatively quickly whereas mobilising a bentonite set-up can absorb much valuable programme time.

2.2 *Environmental benefits*

Polymer fluids can offer significant environmental benefits when compared to their clay-based counterparts. For example, although used bentonite may be classified as a non-hazardous waste, it can be highly polluting if released into the aquatic environment. For projects near watercourses, polymer fluids are preferred over bentonite as they need not pose a danger to fish and in particular they do not build up on fish gills causing them to suffocate (Schünmann 2004).

As the disposal of liquid waste to landfill is banned in many countries, the final disposal of used bentonite slurries can be more costly than the purchase of the original bentonite powder. Polymers are used at perhaps one-fiftieth to one-twentieth of bentonite concentrations and the products can be broken down with readily available oxidising agents such as hypochlorite (bleach) so that after simple settlement the supernatant water can be disposed to sewer (with the undertaker's consent) and the settled fines added to the excavation spoil – ideally for re-use. Thasnanipan et al. (2003) report that in Bangkok the primary reason for switching to polymers was, in most cases, to minimise the environmental issues associated with bentonite fluids. Caputo (2009) also expressed concerns regarding the potential environmental impacts associated with the use of bentonite for the bored piles for a bridge across the Tagus River in Portugal.

2.3 *Improved foundation performance*

As outlined above, operational and environmental benefits are often cited as the main reasons for using polymers rather than bentonite. However, over the last two decades many field studies have been carried out to investigate the effects of polymer fluids and it is now appreciated that they can bring significantly improved load performance for piles, etc. The results of a recent UK case history are summarised below.

To assess the effects of different support fluids and of varying pile bore open times, Lam et al. (2010a) analysed the results from a full-scale field trial in East London, where the ground profile was a layer of made ground underlain by the Lambeth Group and then Thanet Sand. The trial involved the load testing of three instrumented piles, two of which were constructed under a polymer fluid and one under bentonite. The difference between the two polymer piles was the pile bore open time; one was concreted within 7.5 h of the completion of excavation (Pile P1) whilst the other was concreted at 26 h (Pile P2). The bentonite pile (Pile B1) was concreted at 7.5 h.

Figure 2 shows the load-settlement curves of the three piles; both polymer piles behaved similarly and significantly outperformed their bentonite counterpart at the maximum test load of 18 MN – and indeed the pile open for 26 h showed slightly better behaviour than that open to 7.5 h. Analysis of the data from the instrumentation on the piles and supporting laboratory tests demonstrated that the improvement in the load-settlement characteristics of the polymer piles was due to the higher shaft resistance and also the clean pile bases (Lam 2011). The effect of the polymer solution on concrete also was investigated. This showed that the polymer fluid had a similar effect on the strength and stiffness of hardened concrete as bentonite slurry – water from the fluids mixing with the surface concrete being the issue.

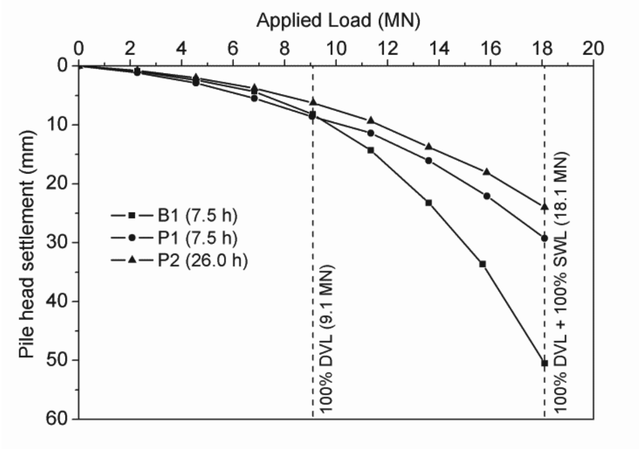

Figure 2. Load-settlement curves of bored piles at the East London test site. DVL: design verification load; SWL: specified working load.

Whilst the above results clearly demonstrate the potential benefits of polymer fluids, these will be realised only if suitable excavation tools are used and there is rigorous base cleaning prior to concreting. Figure 3 shows the auger used for the trial. This had twin flights which prevent suction developing in the fluid column as the auger is withdrawn. Spoil loads onto one flight and the other remains open allowing free fluid flow.

3 FAILURES THROUGH ABUSE OF POLYMERS

The literature reports many case histories of the successful use of polymer fluids. However, failures can still occur and polymer fluids can be used less than optimally as a result of lack of experience and/or understanding of the properties of the chosen polymer. In the following sections, a few examples of common polymer misuses are described.

Figure 3. A twin-flight auger used for the East London trial.

3.1 *Failure to use the polymer at the supplier's recommended concentration*

Suppliers typically recommend that polymer fluids should have a Marsh funnel viscosity somewhat higher than that for bentonite slurries. There is therefore a temptation for users to reduce the polymer concentration and/or for specifiers to require a lower viscosity. However, the Marsh funnel viscosity of an excavation fluid is not an indicator of its performance in the hole rather it is a control parameter to confirm that there is sufficient active material to develop the required fluid properties, such as control of fluid loss to the ground, suspension of cut spoil and inhibition of its dispersion of into the excavation fluid. Reducing polymer concentration may compromise fluid performance and should not be attempted.

3.2 *Viscosity degradation by fluid recirculation*

Lam et al. (2010b) report the results of an investigation of the effects of continued shear on the properties of polymer fluids. The work was carried out on-site using a typical bentonite slurry pipework configuration (Figure 4). The centrifugal pump runs continuously and the fluid is circulated back to the storage tank when the valve in the feed line to the excavation is closed so that the pump need not be repeatedly turned on and off during the excavation. This is an important aspect of plant operation as the storage tank may be at some distance from the excavation. Continuous circulation, although wasteful of energy, is generally regarded as beneficial for bentonite slurries as it prevents settlement and improves hydration.

Two commercially available polymer products based partially hydrolysed polyacrylamides (PHPAs) were used for the study. Each polymer fluid was prepared in accordance with the supplier's recommended procedure and allowed to stand overnight to ensure stable fluid properties. Recirculation through the pump system was then started with polymer drawn off for use in pile bores as required. The Marsh funnel viscosity of the fluid was measured at intervals and the results are shown in Figure 5. The overnight drop in viscosity was due to the escape of fine entrained air bubbles which were present in the fluids after mixing. The effect of air bubbles on fluid viscosity is not well recognised and initial viscosities can be mistaken for working viscosities so leading to under-dosage of polymers.

From Figure 5 it can be seen that once pumping started the viscosity of each of the fluids dropped and continued to do so up to the end of the test. Both PHPAs were of high-molecular-weight (i.e. they were long-chain molecules – longer chain lengths tend to give higher viscosities) and it seems that the chains were undergoing scission as a result of continuing shear in the centrifugal pump and pipework so reducing the fluid viscosity. Indeed the damage was so severe for Fluid B that the initial 65 s viscosity (after overnight ageing) had reduced to 35 s at 22.5 h (after approximately 8 h recirculation) and was tending to that of pure water (28 s).

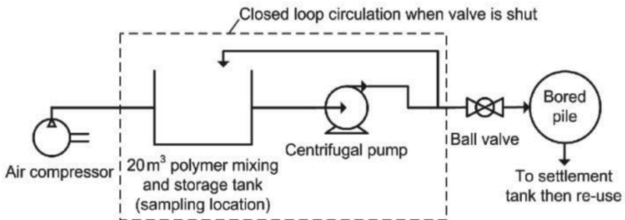

Figure 4. Schematic diagram of recirculation/delivery system.

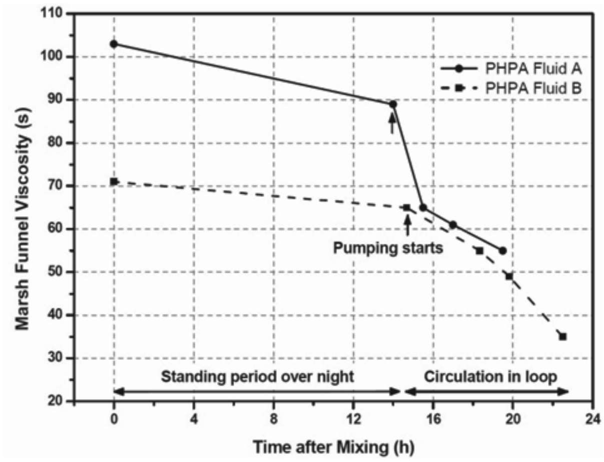

Figure 5. Reduction in viscosity of polymer fluids due to recirculation.

As the fluid was being used for pile excavations the viscosity was boosted by adding polymer directly to the pile bores to maintain stability and there were no collapses. However, had the monitoring programme not been in place, the contractor would not have been alerted to the problem and the pile bores might have collapsed due to the excessively low viscosity.

To avoid viscosity reduction due to prolonged shear in centrifugal pumps, it is recommended that diaphragm pumps are used as they induce less shear and can be designed to stop automatically (so also saving energy) when the pressure rises as a result of closure of the delivery valve. If diaphragm pumps are not available, fluid recirculation should be minimised.

3.3 *Fluid-soil/groundwater incompatibility*

The viscosity and hence other properties of PHPA fluids can be damaged by salts present in mix waters and in the ground. To investigate the effect of salts in mix water, Lam (2011) measured the viscosity of several commercial polymer products over a range of sodium chloride concentrations in the mix water using an Ubbelohde capillary viscometer. Figure 6 shows some of the test results. It can be seen that above about 100 mg/litre sodium chloride, the PHPA fluid lost about 60% of its viscosity in deionised water whereas the blended polymer lost only about 40%. However, for both fluids there was little further effect up to 1000 mg/litre. The effects of salts in mix water are recognised by suppliers and are compensated by increasing the polymer concentration and raising the solution pH with caustic alkalis – though increase in pH may give limited benefit.

In saline soils there should be regular monitoring of fluid viscosity to check for viscosity loss; there are case histories of collapses. For example, on the Vasco da Gama Bridge in Portugal two of the piles had to be re-drilled following collapses which were possibly due to fluid contamination (Bustamante et al. 1998, KB Technologies Ltd. 2000). Schwarz & Lange (2004) also report a case history of pile bore collapse due to high concentrations of salts at a site in Benin. Although simple PHPAs can be adversely affected by salts, engineered polymer systems are available which are more tolerant of ionic species in soils and these should be used in saline grounds.

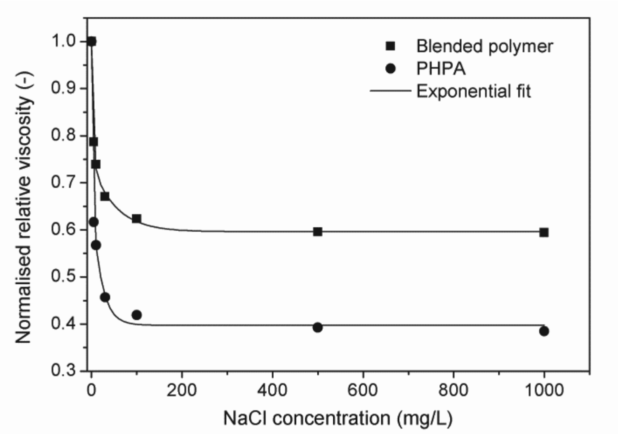

Figure 6. Effect of added sodium chloride on the viscosity of a commercial blended polymer product and a pure PHPA both mixed in deionised water.

3.4 *Loss of active polymer concentration due to repeated use*

The properties of polymer fluids depend on physical and chemical interactions between the polymer molecules in solution. An excavation polymer is thus an active chemical system. Whilst in use in an excavation, polymers tend to sorb onto soil surfaces, especially those of clays and this can beneficially reduce the break-up of lumps of cut soil and the resulting dispersion of fines into the fluid. However, it does follow that the concentration of active polymer drops with use and unless the concentration is regularly re-established the fluid will become little more than muddy water, a condition which the authors have dubbed as ‘flipped’. The system has ceased to be polymer solution with some suspended soil and become a soil slurry with little polymer remaining in solution.

Recognition of the effects of sorption is absolutely key to the management of polymer slurries. With hindsight it is now clear that a number of past problems with polymers can be traced to a lack of appreciation of the need to replenish the polymer lost by sorption and thus a wholly insufficient use of polymer.

To illustrate the effect of polymer sorption, Figure 7 shows the results of a series of tests on a PHPA-bentonite mix with increasing concentration of bentonite; the latter was used as a soil as it strongly sorbs PHPAs. It can be seen that as the bentonite concentration in the fluid increases, the polymer concentration drops and ultimately approaches zero.

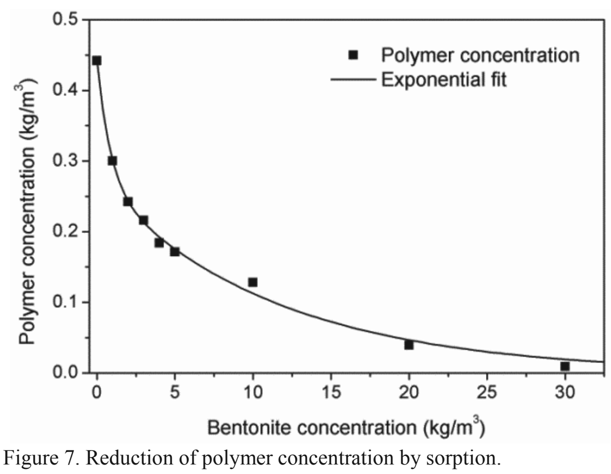

Figure 7. Reduction of polymer concentration by sorption.

4 CONCLUSIONS

Through the use of case histories and recent research findings, this paper has outlined some strengths and limitations of polymer fluids as potential replacements for bentonite slurries particularly for small or congested sites. Strengths include improved foundation performance, simpler site operations and reduced environmental impact. Limitations include reduction of fluid properties due to continued shear in recirculation systems, potential for loss of properties in saline soils and importantly sorption of polymers onto soils – which also can be a benefit as it reduces dispersion of fines into the fluid. To minimise the loss of fluid properties, fresh polymer must be regularly added to the system otherwise a significant degradation in performance of the fluid and potentially the foundation element will occur.

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