High Integrity Polyethylene Stub Flange Connections

by

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Abstract

A novel polyethylene stub flange adaptor is described which allows size-for-size connection, in terms of the respective bores, to iron pipes or fittings. The end load performance of this product is significantly superior to that achieved with conventional polyethylene flanges, especially at large pipe diameters, and the paper attempts to explain the reasons for this. Additionally there is evidence that the sealing performance of mechanical pipeline joints made using this component may be inherently superior, especially where pressure fluctuations occur. Referring to experimental evidence obtained with a slightly different embodiment of the device, it is argued that this potential for enhanced sealing could be fully realised in the case of the hoop-reinforced flange by attention to design factors that would minimise stress relaxation effects within the clamped polyethylene shoulders.

1 Introduction

There has been a massive and sustained growth in the popularity of polyethylene (PE) as a pipe material over the past twenty years, due in part to the "sealed for life" nature of systems made from this material. However, there has also been a small but significant undercurrent of concern about available methods of mechanically jointing welded strings of polyethylene pipe to each other and, more commonly, to iron fittings still found in most pipeline installations. The concerns have fallen into two distinct categories : firstly, cost (including indirect cost) and, secondly, probable long term end loading and sealing performance.

Historically, when PE pipe has been mechanically connected to iron pipe or fittings, either relatively expensive specialist adaptor fittings have been used or else there has been a need for upsized iron pipeline components in order to match up with the bolting circles associated with relatively large traditional PE flange adaptor backing rings. These latter were a direct result of the need to firmly grip substantial PE flange stub shoulders which themselves extended radially outwards from relatively thick PE pipe walls. Any attempt to reduce PE stub shoulder height significantly would have resulted in such joints having totally inadequate end load resistance under the tensile test regimes prescribed for PE pipe connections by British Gas (1) and by the Water Industry (2). In order to avoid the need to use specialist adaptors as above, or the need to upsize the adjacent metal component, so-called "combination" PE flange adaptors appeared on the market. However, these involved temporary down-sizing of the PE pipe and this not only created a restriction in the bore, but also reduced the overall axial strength of the pipeline by up to nearly 50% due to the much reduced wall cross sectional area in the spigot of the down-sized component.

Against the above background the arrival in the market place of the "size-for-size" PE stub flange adaptor was generally welcomed as a cost effective solution (3). The metal reinforcement hoop set into the PE stub flange face of this device allowed the PE stub shoulder height to be reduced, without compromising the axial tensile performance of the assembled joint, to such an extent that (much lighter) backing rings with bolting circles one size lower than previously could be utilised. The three PE flange options just discussed are shown together in Fig.1, in each case butt fused to the same diameter (355mm) of PE100 pipe. The operational benefit of the size-for-size, hoop reinforced, PE flange adaptor is clearly demonstrated in Fig.2.

During successful internal and external Approvals testing of the hoop-reinforced flange, enhanced sealing performance was sometimes observed compared with traditional PE flange adaptors, even though these latter had always performed perfectly adequately in the field provided that the correct bolting up procedure was adhered to. In particular it seemed that the sealing integrity of the hoop reinforced flange was less affected by repeated pressurisation and depressurisation (of the hydrostatic test samples). This impression was seen to be worthy of further investigation because PE systems are increasingly being specified for pumped schemes where significant and repetitive pressure excursions are likely. Total pressures of say 20 barg in the case of PE100 at SDR11 could be commonplace in the near future, especially since current industry investigations are showing existing codes of practice to be unduly conservative with regard to surge allowance in the design of PE pipelines. A general investigation into PE stub flange performance, with the particular intention of exploiting the hoop reinforcement concept, if appropriate, was therefore commenced.

2 Hoop-reinforced PE stub flanges verses conventional PE stub flanges

2.1 Mechanical performance

It may be understood from Fig.3 for example that conventional PE stub flanges are structurally inefficient devices - under tensile loading in Industry acceptance tests (1,2) rotation (as seen in Fig.4) of the PE stub shoulder in the radial-axial plane is resisted only by a combination of (compressive) hoop and ring stresses mobilised in the shoulder, plus radial friction between the shoulder and the steel backing ring and (sometimes) the installed gasket. Since no isotropic material is efficient in bending, it can be no surprise that massive PE shoulders and backing rings are necessary to prevent premature pull out (i.e. before the pipe itself is loaded sufficiently to be yielded) as seen in Fig.5. Similarly it has been found that conventional PE flanges resist pull-out loads better when they are bolted to a rigid metal blanking plate than when bolted to each other, because in the latter case mutual rotation of the shoulders tends to occur. There is believed to be little or no published results of end loading tests on large PE flanges made to existing U.K. or non-U.K. (dimensional only) Standards (e.g.4,5), but in-house tests and also comments from specialist U.K. Test Houses suggest that no "conventional" PE flange adaptor is fully end load bearing ("Type 1" in WRc terminology,2) at a PE pipe size greater than approximately 315mm. Note that although 4 & 5 are dimensional Standards, each only stipulates that backing ring thicknesses need be "adequate bearing in mind the material they are manufactured from".

In contrast, Fig.6 shows the force system generated in a hoop-reinforced PE flange shoulder subjected to tensile loading along the pipe axis as above. The resulting forces utilise the available shear strength of the PE (approximately 3/4 of the tensile strength) to such good effect (Fig. 7) that the main limiting design parameter becomes the available frustro-conical shear path area, rather than (difficult to quantify) bending strength and frictional characteristics. Provided that the shear path length is adequate, and also that it does not pass through the stub shoulder outer surface, joint tensile performance is limited only by the ability of the reinforcement hoop to remain stable under the circumferentially uniform radially inwards reaction loading it experiences. In this context a 355 mm SDR17.6 PE100 hoop-reinforced flange of usual specified geometry, apart from a thicker than standard spigot, maintained its integrity after being loaded to nearly 15% above pipe yield (nearly 50 Tonnes). A load/extension curve for a successful pullout test on a 500mm hoop-reinforced flange is reproduced in Fig. 8 - the clearly defined maximum load where pipe yield occurred may be seen at approximately one third of the way through the total test time.

Physical trials have been carried out to ensure that the relatively highly constrained PE stub shoulders of hoop-reinforced flange adaptors have not resulted in inadequate bending compliance to cope with rough handling in the field during installation. An old-style 300mm iron gate valve was attached via a 355 mm hoop-reinforced PE100 flange (mean wall temperature 12 to 15°C) to a short horizontal length of 355 SDR17.6 pipe which in turn was teathered to the linked forks of a lifting truck. These were then vertically oscillated over a peak to peak distance of 0.1 metres at a rate of 2 to 3 Hertz for 100 cycles. Subsequent inspection of the disassembled flange adaptor revealed no stress whitening or other visible damage at the stub shoulder root or anywhere else.

2.2 Sealing performance

2.2.1 Gasket Issues

In theory gaskets are not necessary to provide a seal with PE flanges (6), since the viscoelastic and creep properties of the polymer will ensure that the flange face is forced into parallelism with its opposite number even under modest long term bolting loads, and that the PE will "flow" into any surface imperfections and thus seal off potential leakage paths. However, about 80% of PE flanged joints in the U.K. Utilities are connected to (often old) iron pipes or fittings and since these may be scarred or pitted a gasket is needed if only to form a protective barrier against further deterioration. Use of a sealing compound would be likely to be counter-productive since it would act as an interface lubricant and thereby increase scope for long term radially inward or outward creep of the compressively loaded PE flange shoulder (see below).

Although in theory a correctly designed O ring would form a very effective seal if set in a suitable groove in a PE stub flange face, (since the long term compression of the groove walls would be negligible as compared to the dimensional operating range of the O ring), the practical difficulty of how to accommodate reliably the occasional need for two such flanges to be joined together has greatly limited their use in practice. However, deployment of elastomeric gaskets having concentric corrugations has been found to be beneficial in the case of all types of PE flanges for two reasons. Firstly surface defects are 'filled' more readily at the lower bolting torques normal with PE flanges, and secondly the lips of the corrugations continue to exert adequate sealing stresses in circumstances when the greater contact area of conventional gaskets would have resulted in excessive attenuation of these sealing stresses.

2.2.2 Physical properties of the PE stub flange shoulder and resulting implications

There would appear to be very little in the literature, about flange sealing performance, that addresses the viscoelastic properties of polyethylene when this material is involved. Confidential British Steel and Victaulic investigations, and work reported by other sources, all concentrate on metal flanges and the bolt prestressing that is required with these to ensure adequate long term gasket loading for a given amount of gasket material relaxation - i.e. it is assumed that the gasket is the only non-fully elastic component in the system. Whereas employing an initial bolt stretch of 0.1% (resulting from torquing up the bolt to near yield, as is recommended in the case of steel flanges) will, it is generally agreed, result in only about a 15% loss in joint interface stress with time as compressive creep relaxation of the gasket occurs, this amount of bolt strain is quantitatively very small in comparison with typical initial compressive strains of at least 2 % imposed on the shoulders of PE flanges (see below). It can therefore be seen that the long term interface stress associated with a PE flange adaptor is likely to be controlled by the compressive creep of the loaded PE shoulder and by very little else.

It is suggested in (6) that PE stub flange bolts should be tightened enough to flatten (if necessary) the PE shoulder and then go on to achieve an initial compressive strain in the shoulder of between 2 to 3%. It may be inferred from uniaxial data in (7) and (8) that the concomitant initial interface stress would be approximately 12 MPa, reducing conservatively to 4 MPa after many years. Whilst this latter value would almost certainly be sufficient to seal against a fluid pressure of 20 bar (=2 MPa), backing ring bowing could result in gasket interface stresses as low as about 2 MPa at locations midway between the bolts (see below). Since the Company referenced in 6 have many years experience of installing flanged PE pipelines that do not habitually leak, it may be safely concluded that the degree of constraint experienced by PE stub flange shoulders usually significantly mitigates against the stress relaxation levels predicted by simple uniaxial models.

2.2.3 Detailed comparisons

In order to engender a better appreciation of the likelihood (or not) that hoop-reinforced PE stub flanges will exhibit inherently better long term sealing performance than conventional PE stub flanges, it is proposed now to compare and contrast some of the possible relative advantages of each design that have not already been discussed in this paper:

a) Conventional PE stub flanges

> The relatively massive PE shoulders may, for the same initial clamping stress from the steel backing ring, be better able to redistribute the resulting internal stresses in order to minimise both long term distortion and net compressive strain in the direction of loading. The latter strain would of course result in reduced overall sealing face stress, the implications of which would depend on gasket characteristics (see comment above about corrugated gaskets).
> The tensile load produced across a conventional stub flange joint by system pressurisation (the Poisson effect) will tend to rotate the or each flange shoulder in the radial-axial plane and beneficially increase the gasket loading towards the outer edge of the sealing face. However, in the event that the pipeline was regularly decommissioned for periods of time there would be some relaxation of this shoulder rotation at each occasion and each subsequent repressurisation

could "inch" the gasket radially outwards in the areas between the bolts. This effect has been witnessed in the laboratory although it can easily be confused with simple gasket displacement caused by excessive internal pressure acting on its inner periphery.

b) Hoop-reinforced PE stub flanges

The significantly radially smaller shoulders of this design result in a much reduced lever arm effect from the tightened up backing ring - thus it is easier to achieve uniformity of loading and there is greater tolerance to uneven torquing (less potential for the backing ring to tilt). Also, since the backing ring loading is applied with lower moment, sealing face stresses are radially more uniform and the risk of leakage due to localised poor surfaces is reduced.
The insert hoop confers very high ring stiffness to the PE shoulder and there is therefore very little rotation in the radial-axial plane. As has been shown elsewhere for GRP stub flanges (10), this inherently results in enhanced gasket loading near to the bore (given that in currently available hoop-reinforced flanges there is a slight reveal in this area due to the presence of the recessed insert hoop).
The system pressure-induced tensile load across a PE pipeline connection comprising hoop-reinforced size-for-size stub flanges will be lower due to the decreased effective cross sectional area of hydrostatic loading at the joint interface. The loaded area will extend outwards to approximately the half way point between the backing ring inner diameter and the inner bolt circle diameter for both designs. In practice the reduced bolting circle of the hoop-reinforced flange results in an effective cross section area (and therefore hydrostatic load) some 20% lower than that for a conventional flange.
It has been estimated (source retained but unknown) that a reduction in bolt separation around the backing ring of 50% will reduce the detrimental bowing effect of the latter by 87%. Since for similar nominal pipe sizes the bolts are typically 15% closer together in the case of the hoop-reinforced design, the bowing effect would be expected to be reduced by about 25% were it not for the fact that in practice *thinner* backing rings are employed in hoop reinforced flanges in order to maximise cost effectiveness (the rings are designed to be thick enough to provide full end load performance in every size available).

It may be inferred from the above comparisons that in all probability the sealing performances of each design, as currently embodied, are on balance not that different. Controlled experiments in the laboratory have confirmed this to be so (although relative abuse tolerance has not yet been quantified). However, it may equally be surmised that the potential for better sealing with the hoop-reinforced design concept is greater. In the laboratory it has been found that, although bolt torques drop off more with time (due it must be assumed to reduced shoulder bulk), the hoop-reinforced flange nonetheless manages, when similar gaskets are employed, to maintain a satisfactory seal at these lower prevailing clamping loads. Efforts are now therefore being directed towards cost effectively constraining the relatively compact shoulders of the hoop-reinforced design in order to reduce long term stress relaxation effects.

An extreme but very relevant example of the sealing benefits of so doing has manifested from work recently carried out on sealing stubs for thin PE liners that need to be terminated at screwed steel connections in the offshore industry. The lining stub configuration (Fig. 9) is identical with that discused in this paper, except for scale - the lining shown is only 6mm thick - but very importantly the outside diameter of the stub shoulder is totally constrained within the recess in the bore of the connector. A test sample similar to that in the illustration was subjected to an internal pressure of nearly 350 bar at ambient temperature for several hours, and then at 90°C for two 8hour periods, with no apparent leakage at the stub interface. The excellent high temperature (for PE) sealing performance achieved has given confidence that totally effective long term sealing can be expected at the same high pressures at 20°C or thereabouts. It is clear therefore that the hoop, although primarily intended to help provide a secure anchorage against thermally induced axial loads within the lining (which it managed to do), also effectively prevented all radially inwards creep of the compressed stub shoulders. It therefore seems realistic to expect that a modest level of physical constraint to the outer surface of the "normal" hoop-reinforced stub flange shoulder could provide a total guarantee of long term sealing integrity in a flange jointed Utility pipeline subjected to fluid pressures at least one order of magnitude less than that in the offshore application described. For interest, an early approach (11) to providing a high pressure seal within a lined steel connection is shown in Fig.10.

3. Conclusions

With the advent of new grades of polyethylene pipe materials, and also more onerous applications, there is increasingly a need in the Water Industry for cost-effective mechanical joints having no bore restrictions and that are able to totally resist long term, frequently varying, operational pressures.

A novel type of PE stub flange adaptor, incorporating a reinforcing hoop in the sealing face, has been successfully developed and marketed on the back of immediately obvious operational and functional advantages - primarily economical size-for-size capability together with ease of handling, but having also full end load bearing tensile performance.

This paper has attempted to provide some insight into the method of working of the hoop-reinforced stub flange adaptor, and it has gone on to show that further development of the product could enhance its long term sealing performance to a very high level.

It will be essential for any resulting modifications to the product to be very economically engineered, in order that its cost remains attractive to the end user. In this way the hoop-reinforced flange adaptor may be expected to help expand the market for medium and large diameter plastic pipelines still further.

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Fig 1. Three ways to skin a cat

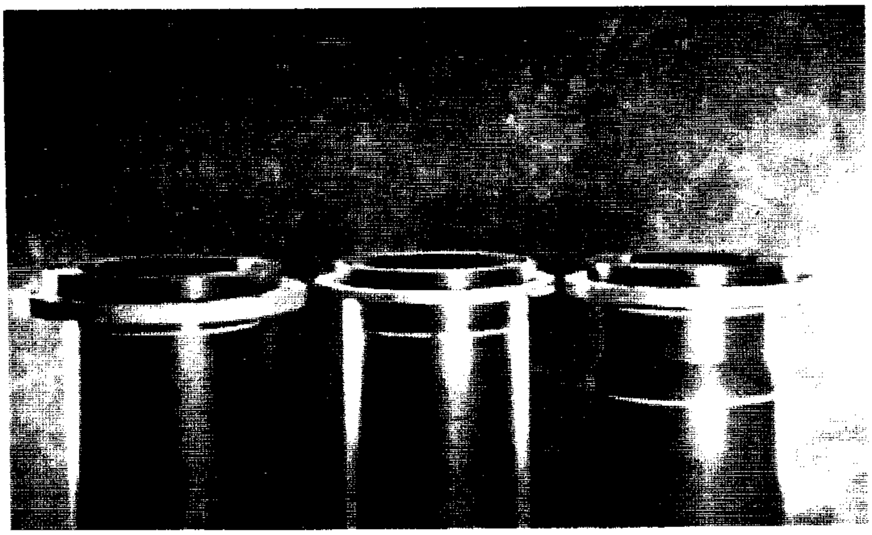
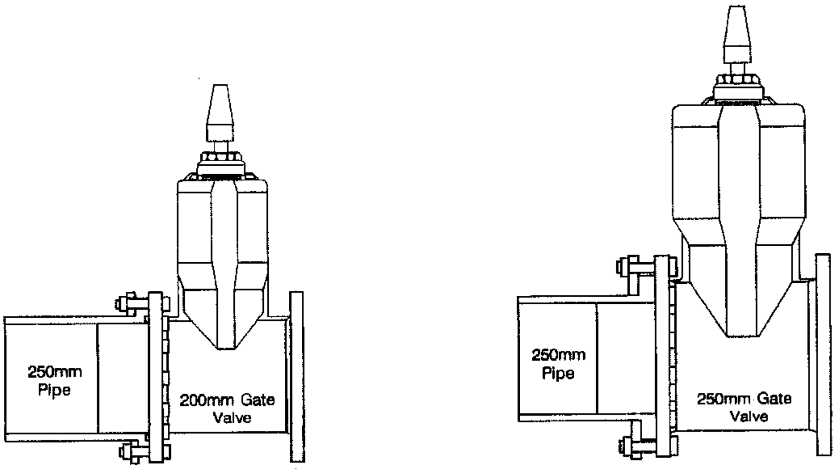


Fig 2. Operational benefit of hoop reinforcement



Hoop-reinforced flange

- connects 250mm PE pipe to 200mm valve

Traditional

- requires 250mm valve

Fig 3. Forces in traditional PE stub flange joint under end loading

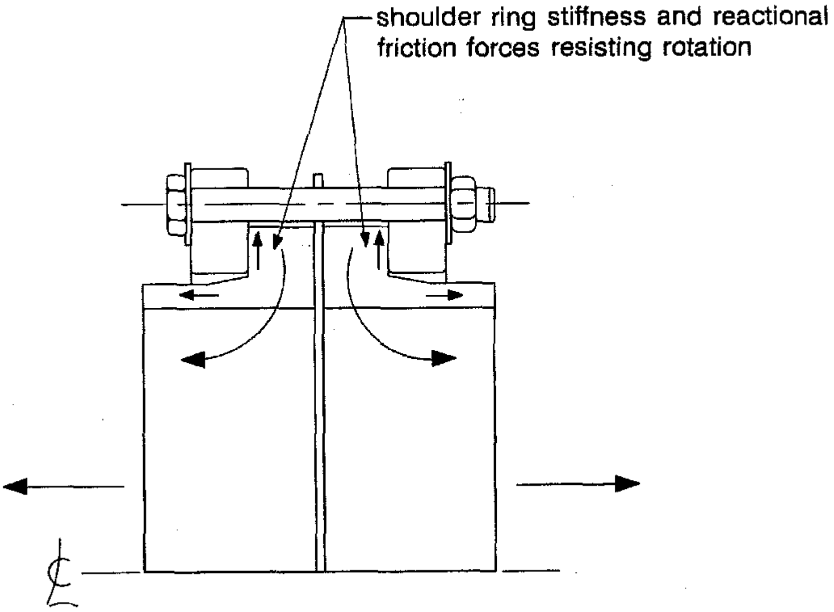


Fig 4. Shoulder rotation with traditional flange joint under tensile loading: 315 SDR11, PE 100, 45 tonnes (80% of pipe yield load)

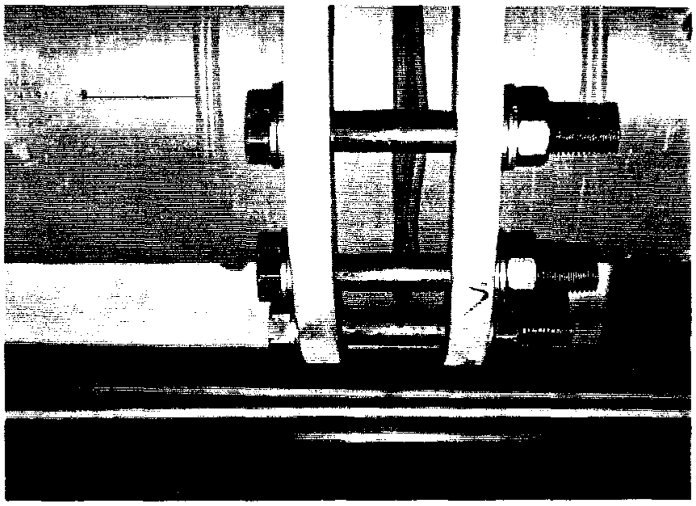


Fig 5. Standard PE flange joint, having separated before pipe yield: 180 SDR11, PE 100, 17 tonnes

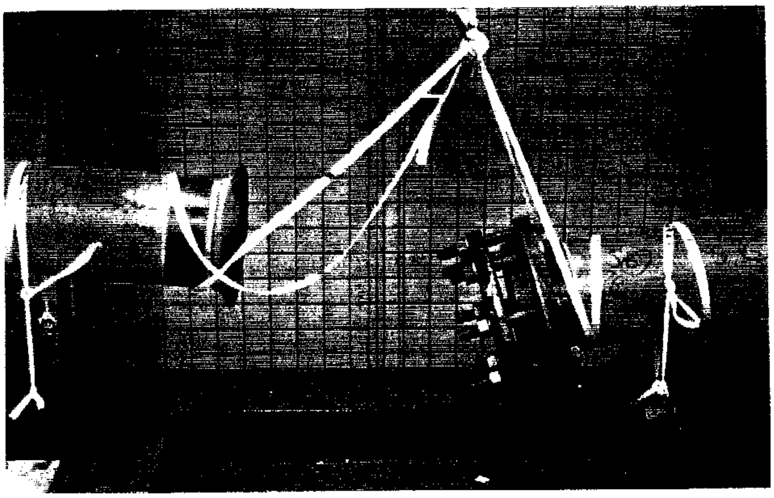


Fig 6. Forces in hoop-reinforced PE stub flange under end loading

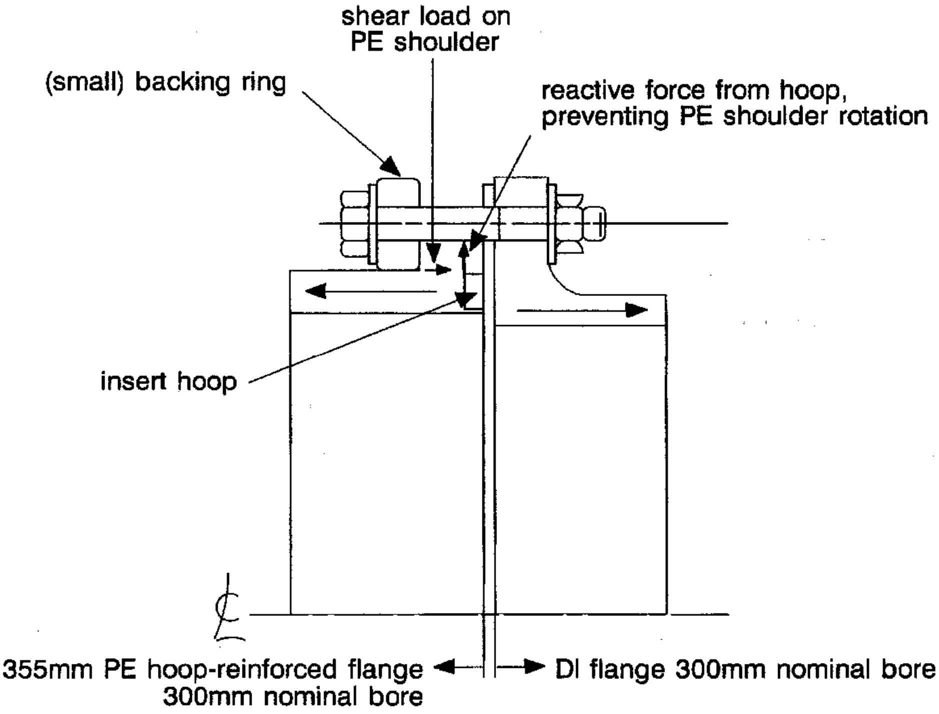


Fig 7. Hoop-reinforced PE flange joint, dismantled after pulling to full pipe yield. 355 SDR17.6, PE 80, 36 tonnes

Fig 8. Load/extension curve for 500, SDR 17.6 x 450 PN16 hoop re-inforced flange joint

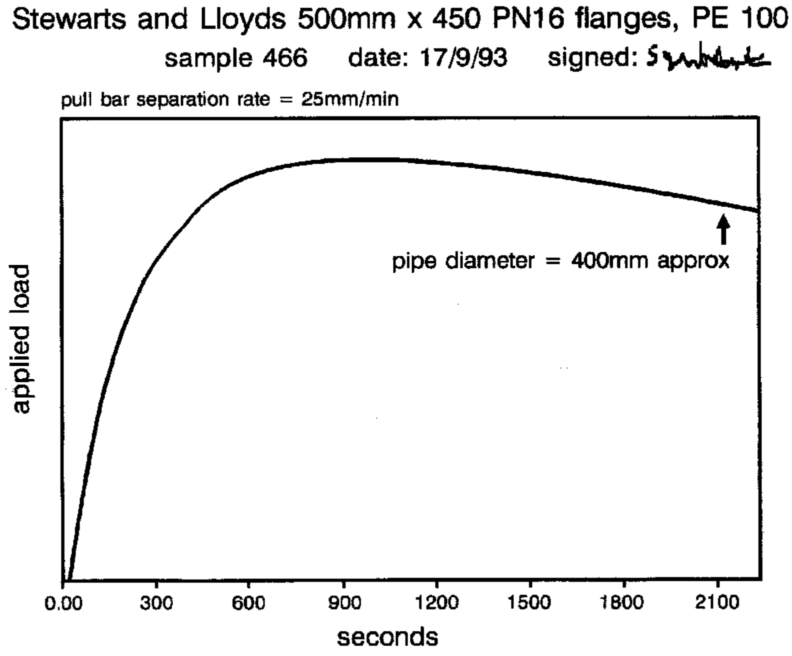


Fig 9. Polymeric lining with integral hoop-reinforced stubs within a screwed connector

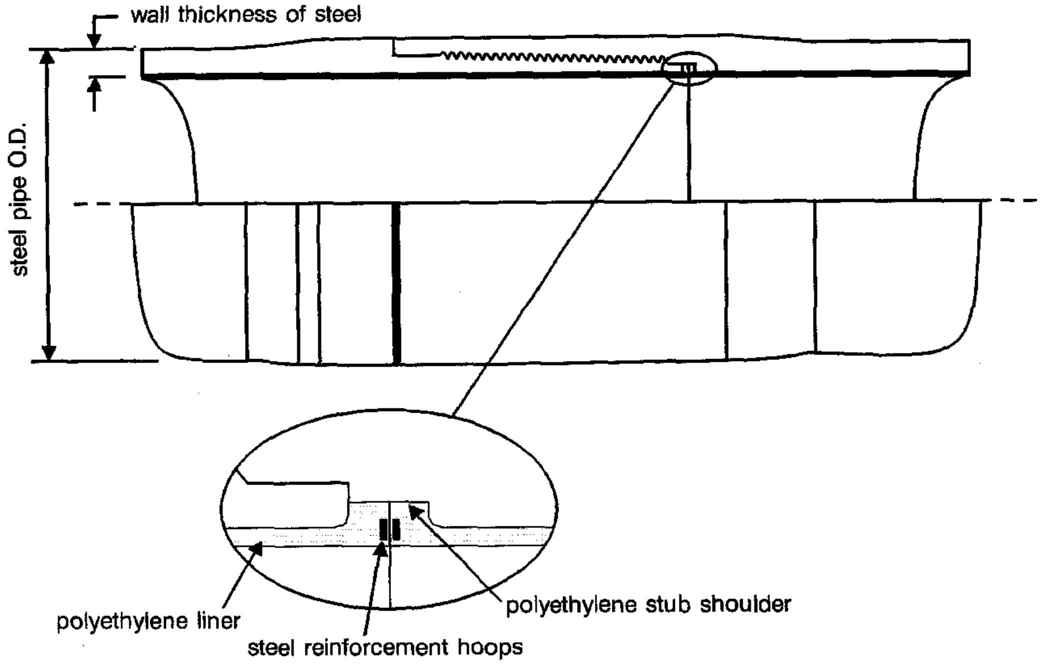


Fig 10. Early PE lined screwed connector methodolody