"Design of Thermoplastics Pipes: Prediction of Pipe Deflection versus Measured Values"

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SYNOPSIS

Extensive field trials are being performed in a project sponsored by TEPPFA and APME,to obtain well documented information about the behaviour of buried thermoplastics pipes, as outlined in the paper by Alferink, Björklund and Kallioinen (Ref 1). This information is of vital importance to obtain a workable design method for buried pipes. Tests were carried out using different pipe materials (PVC,PE,Steel), different pipe stiffness, buried at depths varying between 1.15 and 3 metres, using clay as well as sand as sidefill, and by installing them in a compacted as well as in a dumped way. Pipe deflection and strain measurements were carried out, when the pipes were loaded by soil, traffic and internal hydrostatic pressure. European design experts were put to work with the soil and pipe parameters, and asked to carry out the design using their own or their national design method. Afterwards, they were provided with the results of the measurements carried out on the pipe as well as on the soil, allowing them to asses their design. Then in December 1997 a workshop took place with those experts to discuss the results and with the intention to obtain a good basis for establishing an unified design method for all buried pipes, and by that assisting current CEN work on the same subject. This paper presents a first glance of the results of the work carried out so far. The results show that consistency between installation and design practice is one of the major factors to be considered.

Based on the results as found in the field studies, the authors recommend a design approach which safely predicts the behaviour of buried pipes.

INTRODUCTION

The advantage of using flexible pipes in these kind of studies is that the performance of the pipe soil system can be easily determined, by means of deflection measurements. In case of more rigid pipes one has the problem, that the deflection gets low, and as such does not easily allow determination of the effect of different parameters in a significant way. When performing these kind of studies on the more rigid pipes, one is compelled to use strain gauges only. The disadvantage is that in such a case already before the tests the location of measurements is fixed. Next to this the practical variability existing along the pipeline is difficult to assess, when using strain gauges. Another complicating factor is again the low values that are measured in comparison to the accuracy of the measurements. In outdoor conditions relative accuracies of strain gauge measurements better than 5% are hardly feasible. Therefore flexible pipes in the low stiffness range were used in this study in combination with rather poor installation conditions. Next to satisfy the wish of the experts to look for the limit states, it also permits determination of the effect of the different parameters as well as possible. The lowest nominal pipe stiffness used is 2 kN/m^2 . This low pipe stiffness is normally not used for buried thermoplastics applications, although in the past good experience has been gained with these pipes, especially in the Netherlands.

The common pipe stiffness used for buried applications is 4 kN/m^2 and up.

Another important aspect, which is mostly not considered in studies of this kind, is that unlike soilbox testing, realistic workmanship is demonstrated. The requirement for this to be achieved is that sufficient pipe length shall be installed to allow the contractor to do his routine installation job. For that reason pipe lengths of 20 meter were used. Next to the advantage of obtaining normal workmanship, also the variability within each installation condition of the performance of pipes will become apparent.

CURRENT EUROPEAN DESIGN METHODS

There are exists many different design methods for buried plastics pipes. Some of them are very detailed and claim a high degree of precision, where others are more general and don't chase such a high precision. In most cases the latter group is very much based on actual field experience whereas the first group is based on theoretical exercises. CEN TC164/165 JWG1 originally defined six methods which can be used for the design of buried pipes. They can be found in CEN EN1295. Meanwhile the JWG1 formed a task group with the objective to come to one unified method. Table I shows an overview of most of the existing methods.

Table I : Well-known established design methods

Method	Country	Method	Country
EN1295		**Other methods**	
ATV127	Germany	WG14	WG14 of TC155 (GRP)
Materials Selection Manual	UK	CalVis	Wavin
Fascicule 70	France	Bossen	NL/Polva-Pipelife
Önorm B5012	Austria	TAMPIPE	USA
VAV P70	Sweden	AWWA C950	USA

The first known design method for buried flexible pipes (Corrugated steel culverts) was developed and published by Lazard (Ref.2) and utilized further by M.G. Spangler (Ref.3). In general the approach was to carry out a structural analysis on a ring loaded by external soil pressure. A soil load distribution was developed for this case and from this the relative ring deflection was deduced. The general appearance of the formula is shown below :

$$(\delta/D) = K_x Q/(aS_p + bE_s) \qquad (1)$$

where :

(δ/D)	=	Pipe deflection	[%]
Kx	=	Load factor	[-]
Q	=	Vertical soil load at crown level	[kPa]
a,b	=	multiplication factors	[-]
S_p	=	Pipe ring stiffness	[kPa]
E_s	=	Soil stiffness	[kPa]

Spangler also discovered that the pipe deflection in the steel pipe increased with time, until the soil around the pipe has settled. In order to quantify this effect he introduced the deflection lag factor. A value of 1.5 is often recommended for this factor.

In Ref. 4 it is shown that all established national methods are built up in a similar way referring to the original Lazard / Spangler approach. Only the coefficients are given different values. Some methods are developed from a very theoretical point of view, where others try to cover the actual performance of the pipes as accurately as possible, by considering field experience from measurements. For instance in the VAV P70 method, Molin recognized that the pipe deflection can not be fully predicted by theoretical rules, amongst others because of the fact that the actual field condition and installation performance can never be accurately predicted. For that reason he introduced so-called installation and bedding factors in the same way as also referred to in Ref. 5. A method with a similar approach is the method proposed by Bossen. Another method based on practical experience is the CalVis method. It uses an analytical approach to a certain extend and involves the results of experiments to make the method fit with results of actual field tests.

In general all the methods commence with the selection of a soil group.

Soil stiffness are based on soil groups and the estimated proctor density to be reached during installation, are listed in tables. Next to this the methods need the depth of cover and the traffic load description. The more detailed methods need much more information among which, trench shapes, and discriminated soil groups for bedding, native soil, embedment and topfill.

It is obvious that the more detailed the method, the more detailed information about the site shall be known, and also one needs to be sure that in the end the anticipated input values, especially about the soil are realized, i.e the more detailed the theory, the closer the supervision and control of construction must be.

TEPPFA / APME TRIALS

The background of the trials as well as the approach chosen has been extensively discussed in Ref. 1.

Three types of installations are used, which are described below:

Careful installation, designated as "Well"

The trench bottom is flattened, and stones or other hard objects are removed from the trench. In cases where the bottom is very stiff, the soil is loosened up a little. At the 'Sand' test site in Haarle, where the bottom has a moderate stiffness this loosening was not performed. At the 'Clay' test site in Wons, imported backfill was used to create a bedding layer of approximately 20 cm. This layer was not compacted. After the bottom has been prepared, the pipe is positioned and the native soil (Haarle) or the imported backfill (Wons) is placed alongside the pipe up to the crown of the pipe, meanwhile exercising foot tamping to create a good haunching zone. Then a mechanical compactor was used to compact the side fill up to a relative density of 98-100 % standard proctor .Then the next layer of about 30 cm was placed and compacted in the same way as the sidefill. This procedure was repeated until the trench was completely filled, or at least a depth of cover of 90 cm was obtained. The rest of the backfill was dumped and compacted by a machine digger.

Moderate installation, designated as "Moderate"
This type of installation was only performed in Haarle. In this case the soil is not placed in shifts of 30 cm each, but the pipe was covered by the soil up to a level of 60 cm above the pipe, after which the compaction was carried out. The placement of the soil around the pipe was done with some care.

Careless installation, designated as "Non"
In this type of installation no care at all is exercised. The embedment and backfill in Haarle are both dumped by a machine digger. This is the worst condition one can think of. After the trench is completely filled, the machine digger compacted the soil. At Wons slightly more care was exercised. The big weak lumps of clay were placed on the pipe with little care.

The installation work was well monitored by measuring as well as by filming.

RESULTS OF FIELD TRIALS

The result of the field trials are summarized in this section. In Table II , an overview of the tests and design cases are listed.

Table II : Overview of tests and design cases. ('Haarle' : 1-12, and 'Wons' : 13-16)

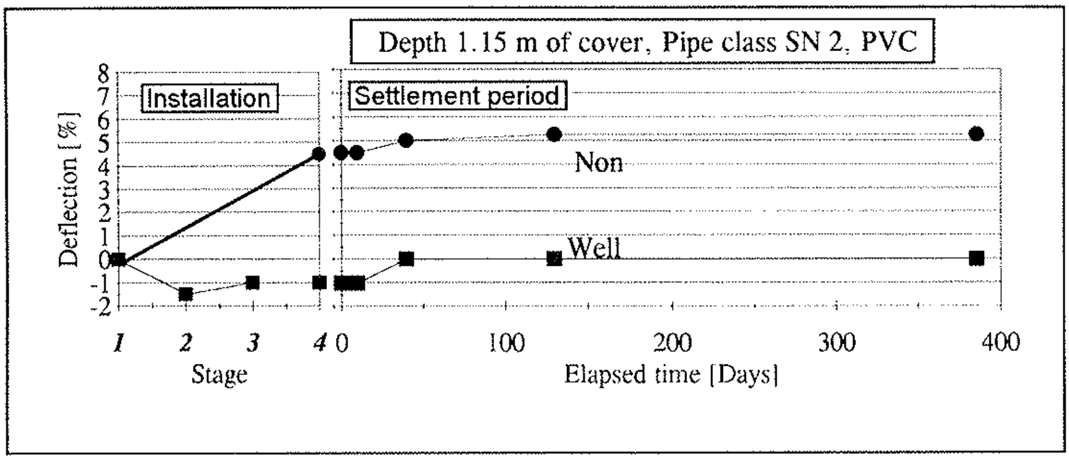
Case	Soil type	Depth of cover [m]	Diameter [mm]	Nominal stiffness [kPa]	Material	Compaction
1	Sand	1,15	315,00	4,00	PVC	Well
2	Sand	1,15	315,00	4,00	PVC	Non
3	Sand	1,15	315,00	2,00	PVC	Well
4	Sand	1,15	315,00	2,00	PVC	Non
5	Sand	1,15	315,00	6,00	PE	Well
6	Sand	1,15	315,00	6,00	PE	Non
7	Sand	1,85	315,00	4,00	PVC	Moderate
8	Sand	1,85	315,00	4,00	PVC	Non
9	Sand	1,85	315,00	2,00	PVC	Well
10	Sand	1,85	315,00	2,00	PVC	Non
11	Sand	1,85	323,90	4,00	Steel	Well
12	Sand	1,85	323,90	4,00	Steel	Non
13	embedment=Sand	1,15	315,00	6,00	PE	Well
14	Clay	1,15	315,00	6,00	PE	Non
15	embedment = Sand	3,00	315,00	6,00	PE	Well
16	Clay	3,00	315,00	6,00	PE	Non

Figure 1 shows a graphical presentation of the development of the average deflection during and after installation for both installation conditions "Well"and "Non". The first stage of installation represents the compaction of the first embedment material. As can be seen the deflection becomes negative in case of the "Well" installation, meaning that the pipe deforms into a standing egg shape (Columbus effect), which may easily occur for a well compaction around a pipe with low ring stiffness (2 kN/m^2 in this case). The second stage show the deformation of the pipe after the next embedment layer is applied and compacted. Whereas the last and third stage in the installation shows the deflection after completion of the installation.

From that point onwards, the settlement period of the soil pipe system starts, which is shown in the second part of the graph.

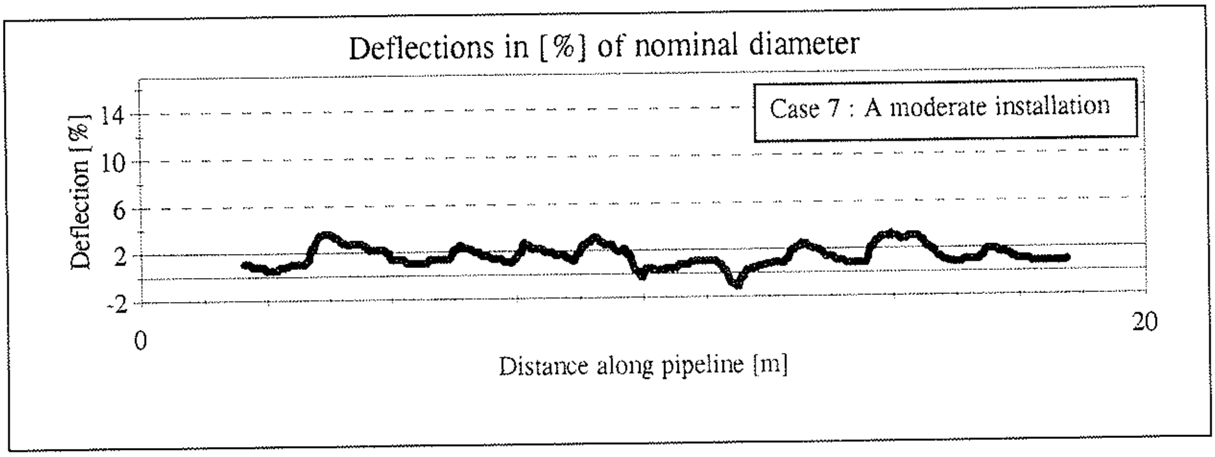
The Careless "Non" installation condition shows the deflection immediately after installation of the pipe. From the graphs it can be concluded that the deflection of the pipe is for the majority achieved by the installation process.

Figure 1: Deflection development during and after the installation process.(Cases 3 and 4)



Next to average deflections, which are of importance for the serviceability aspects of the pipeline system, also the maximum deflections are of interest, especially when the most important design criteria, that of structural failure is considered. In Figure 2 an example is presented showing the variability along the pipeline.

Figure .2 : Deformation pattern along the pipeline (Case 7)



Variability is caused by the effects of uneven bedding, differences in compaction along the pipeline, differences of the stiffness of the native soil along the pipeline, and additional variations in workmanship when performing the job. Local circumstances, like available space, field logistics, whether conditions, control of groundwater table and embedment material used, influences the variability.

COMPARISON WITH DESIGN METHODS

As was explained above, the design experts carried out the design based on the generally available soil and pipe information. This comprised of a grain size distribution of the soil allowing the right choice of the soil group, nominal pipe properties and the installation conditions anticipated. It is obvious that if a geotechnical design of category 1 according to Eurocode 7 (Ref. 1) would be made, then this information is rather extensive, whereas if a category 3 design has to be made, more information should maybe be available.

The comparison between measured and predicted values are shown in Enclosures 1 and 2. Enclosure 1 shows two graphs for the installation types designated "well" and "moderate". The first graph shows the comparison for the initial average deflections, whereas the second graph shows the comparison for the initial maximum deflection. On the horizontal axis the measured deflections and on the vertical axis the predicted deflections are plotted. Values that are plotted above the equal (cross) line, overestimate the deflection, whereas the values located under the cross line represent underestimated deflections. It is shown that most methods predict the initial average deflection slightly conservatively. It is also shown that for instance the Önorm method does not calculate an average deflection. The initial maximum values are however more often underestimated, especially by ATV, Fascicule and Önorm. The VAV P70, Bossen and CalVis method stay on the safe side of the equal line.

In Enclosure 2 the same type of graphs are shown, but now for the installation types designated as "Non". Here it can be seen that several methods rather often underestimate the pipe deflection. Again CalVis, VAV P70 and Bossen stay in most cases on the safe side of the equal line, so indicating that they predict higher levels than measured.

The ATV127, Önorm B5012, WG14 and Fascicule 70 method provided updated values after both the results from the 'after installation' soil and pipe deflection measurements had become available. All four methods were able to adjust the values in away that they coincided with the equal line, so simulating as far as possible the measured results. It shall be stated that the engineer has no access to this kind of information in real life projects. In most cases the methods used another soil group then originally anticipated. When using the methods mentioned above, more extensive soil data by field surveys shall be available, or more care shall be exercised by the designer when imterpreting the grain size distribution.

It was shown that the CalVis, Bossen and VAV P70 method predicted the maximum values rather well, without any secondary adjustments. The good fit of the VAV P70 method is very much based on information gained from pipe deflection measurements in operational sewers (Ref. 6). The other reason is that concerning the VAV P70 method it is a well known fact, that the method does not take into account any differences due to soil variations within the granular soil series. The method only considers ***granular*** soils (as a whole) or ***clayey*** soil. Thus, all pipe deflections in Cases 1-12 have been calculated with E-moduli valid for granular soil in general under various degree of compaction as given in the standard graph of the method.

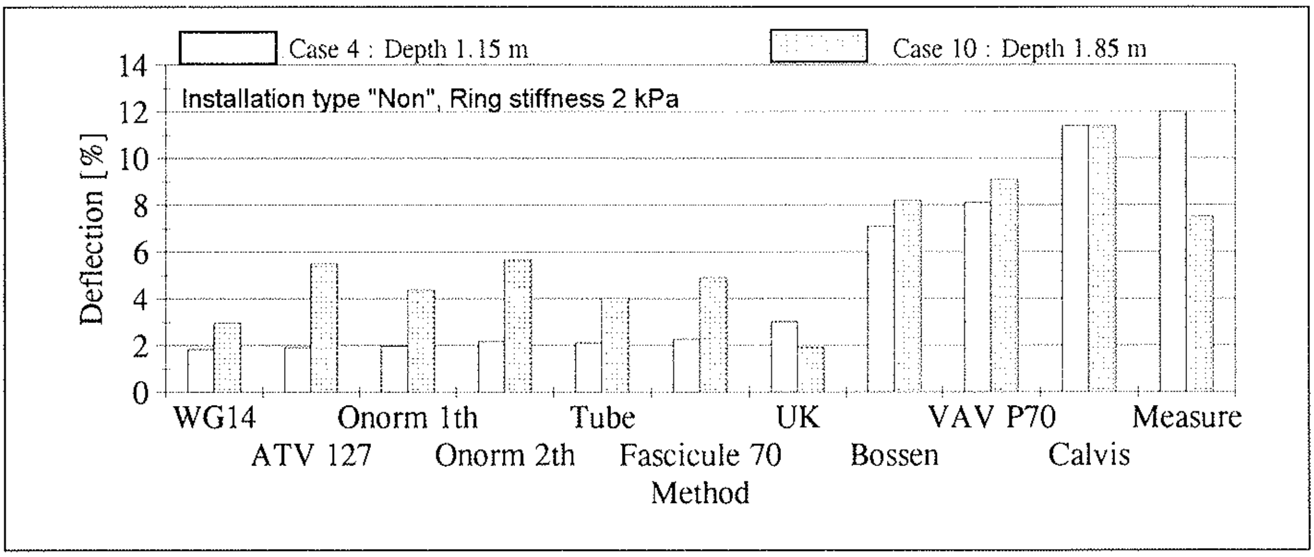
An advantage of the VAV P70 method from practical engineering point of view is just, that it does not ask for detailed knowledge of the type of granular soil for reaching a reasonably good result as to the predicted deflection versus the measured. This situation, recognized by a limited amount of information about the soil conditions when it comes to the final installation work, is quite common for a design engineer. Also in the test site 'Haarle' it was shown that the native soil changes from sand to silty sand over a depth of less than a metre (Ref. 1). For some more sophisticated methods needing detailed knowledge about the soil, even in the granular series, it would be problematic to handle the situation where the native soil is used as backfill again.

It can be concluded that from the established methods, the Swedish method is probably the most robust. It shall however be realized that for very good installations and / or good soils the method overestimates the pipe deflection considerably. However it is also a known fact that in such cases actual deflections are so low that their predictions by design is of no concern for thermoplastics pipes!

In the above section the general comparison between design methods and field measurements were shown. Now some specific parameters will be studied in more detail. The deflections shown are all initial maximum deflections (immediatly achieved after installation), unless otherwise indicated. It shall also be noted that the WG14 method calculates only the average deflection. Nevertheless the values are also shown in the graph. It shall further be emphasized, that the demonstration of the effects are based on the comparison of two design cases. Sometimes another choice would have shown a slightly other effect. In the near future the effects of the different parameters will be further quantified.

Effect of depth of cover. The result is shown in figure 3.

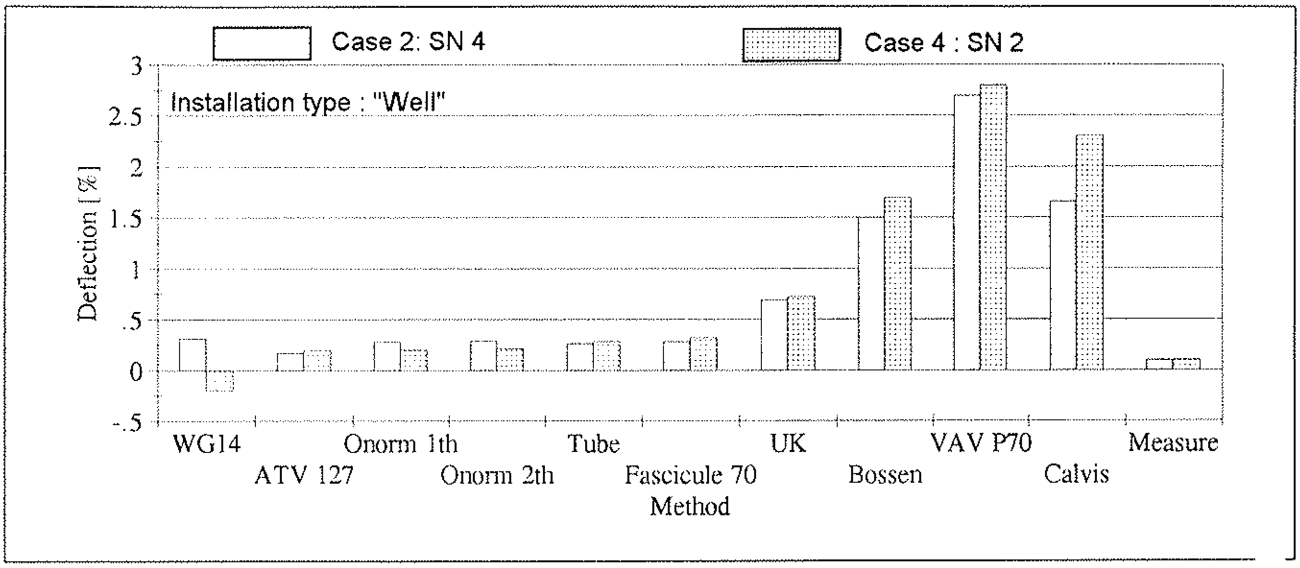
Figure 3 :Effect of depth of cover



The graph shows the different methods used on the horizontal axis. The method "Measure" represents the result of the measurements. The values evaluated are the initial maximum deflection. The graph clearly shows that most methods consider depth as a serious effect. The result shows that in reality deflection does not increase with depth. Most methods however consider depth as causing an increased deflection. The results indicate that in reality the deflection is not steered by load. This will be subject for further analysis in the future.

Effect of pipe stiffness. The result is shown in Figure 4.

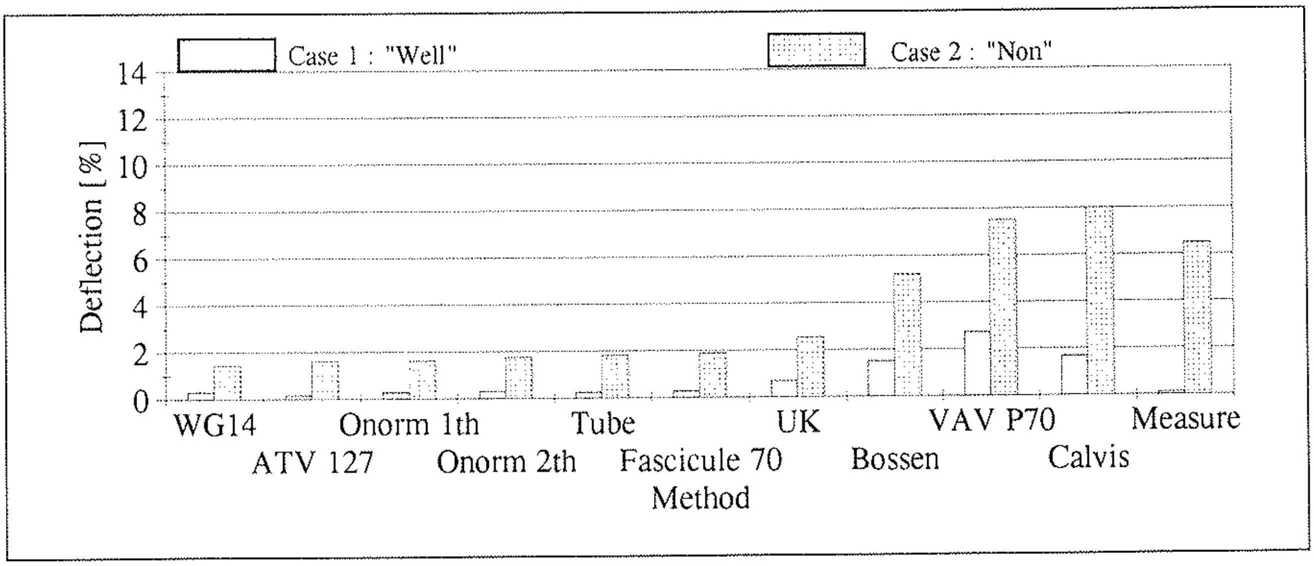
Figure 4 : Effect of pipe ring stiffness.



It is shown that most methods consider pipe stiffness as not significant in case of well installed pipes.

Effect of installation. The result is shown in Figure 5.

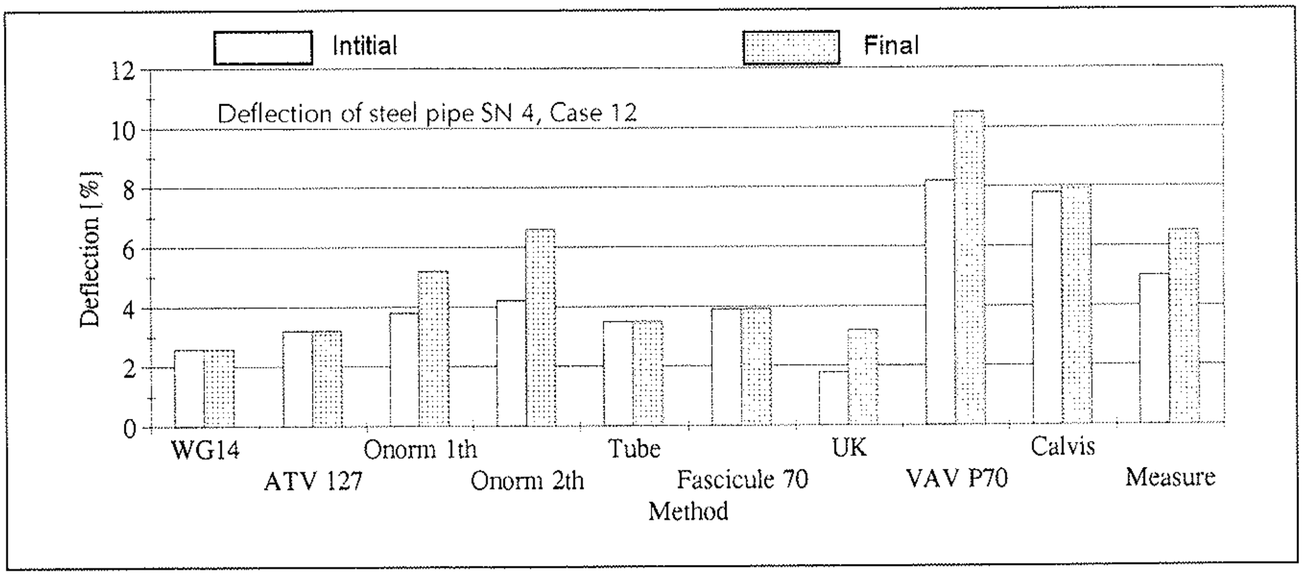
Figure 5 : Effect of installation



All methods respond to the less good installation by predicting higher deflections, however also here the more to practical experience related methods like Bossen, VAV P70 and Calvis come closest to the actual measured value.

The effect of elapsed time of buried pipes. The result is shown in Figure 6.

Figure 6 : Effect of elapsed time.



Discussions about the use of short term and long term moduli of the pipe material have continued fro many years. In Ref.4,6 it is explained and proved that the soil settlement controls the pipe deflection, and not the creep ratio of the pipe. In order to verify this further in this trial, next to thermoplastics also steel pipes were buried. Figure 6 shows the result of the measurement and the predicted values, where for the measured value the 1 years value is read. It is clear from this comparison, that time dependency is only covered by the Önorm, the UK, the VAV P70 and by CalVis. The other methods do not consider the settlement of the ground, since they all showed a time dependency when evaluating the behaviour of the thermoplastics pipes involved, but no time dependant effect was considered when evaluating the steel pipes.

DISCUSSION

When one looks carefully at the proceeding of the installation work as well as at the design of the pipes, than the following discrepancy is seen.
During installation, the pipe is placed on a more or less flat bedding, depending on the installation method used. Next to this the stiffens of this bedding is not constant along the pipeline. The above will result in beam bending effects and indirect transferred loads to the cross section of the pipes. Especially in axially stiff pipes this effect will be greater than when the pipes are quite flexible in the axial direction. After the pipe is placed on the bedding, the first embedment material is placed around the pipe, and compacted.
The way of compaction, which is for instance influenced by the water content of the soil or in case of cohesive soil the strain path, loads the pipe at one springline. The other springline (other side of the pipe) is still facing uncompacted soil.

After also this part is compacted, more soil is backfilled and compacted again. The above process is repeated until the whole trench is filled with soil. If then on the other hand the design methods are considered, it appears that they calculate the response of a ring that is loaded by an arbitrary load distribution. The models are so-called load driven. The initiator is the soil load or the traffic load, which acts on a ring. In most methods measures are taken to reflect the effects of load shedding and concentration, but in the end it is a load distribution on a pipe ring. From the above it would not be strange to conclude that it is more luck than wisdom when analytic methods predict closely an actual pipe deflection. In line with this it is fully clear that the methods utilizing results from practical pipeline installations are better in prediction than the pure analytical ones. For instance the VAV P70 methods uses a load approach to calculate the pipe deflection, but adds a few significant terms reflecting field practice.

Now the above might give the impression that analytical methods are of no value, however it is quit clear that the analytical methods contain some features which are very well useable to develop an understanding about the pipe-soil interaction.

RECOMMENDED APPROACH

Based upon the results of the TEPPFA / APME project the practical limit of sophistication for a calculation method has been shown. A sophisticated analytical model with adaption to category 3 of Eurocode 7 will describe an idealized situation with practical application only where soil property measurements, and construction supervision procedures are equally sophisticated. This as a background we would like to present the following approach.

The authors would recommend to follow the ideas explained in Ref. 1 to make use of the prescriptive measures method, since a lot of experience is available and published. As far as the category 3 types of design are concerned, covering pipes with extremely low stiffness, and / or the potential danger of soil settlement along the pipeline, it is recommended to use the observational method in conjunction with calculations regarding the prediction of the pipeline when settlement differences along the pipeline occur.

Next to this the project group of TEPPFA has planned to publish a simple design table where customers can easily obtain a safe deflection figure depending on soil type, installation and pipe stiffness. If however, calculations are requested, it is recommended to use the VAV P70 design method. The project group will extend the basics of this method in such away that it can also be used for the more rigid pipes

CONCLUSION

* Although extremely poor installation conditions and rather low pipe stiffness have been used, no pipe failure or buckling has occurred, confirming the huge safety thermoplastics pipes exhibit when used under more normal conditions.

* Detailed design methods pretend to produce accurate results, however the limiting factor is the workmanship utilized in the field.

* Pipe installation is the most important parameter affecting the deflection.

* Depth of cover and pipe stiffness are hardly significant. Currently, work is being undertaken to quantify the above more precisely.

* The time dependent behaviour of buried pipes is essentially dictated by the soil settlement, and not by the visco-elastic behaviour of the pipe.

ACKNOWLEDGEMENT

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Note :
TEPPFA : The European Plastics Pipes and Fitting Association
APME : Association of Plastics Manufactures in Europe

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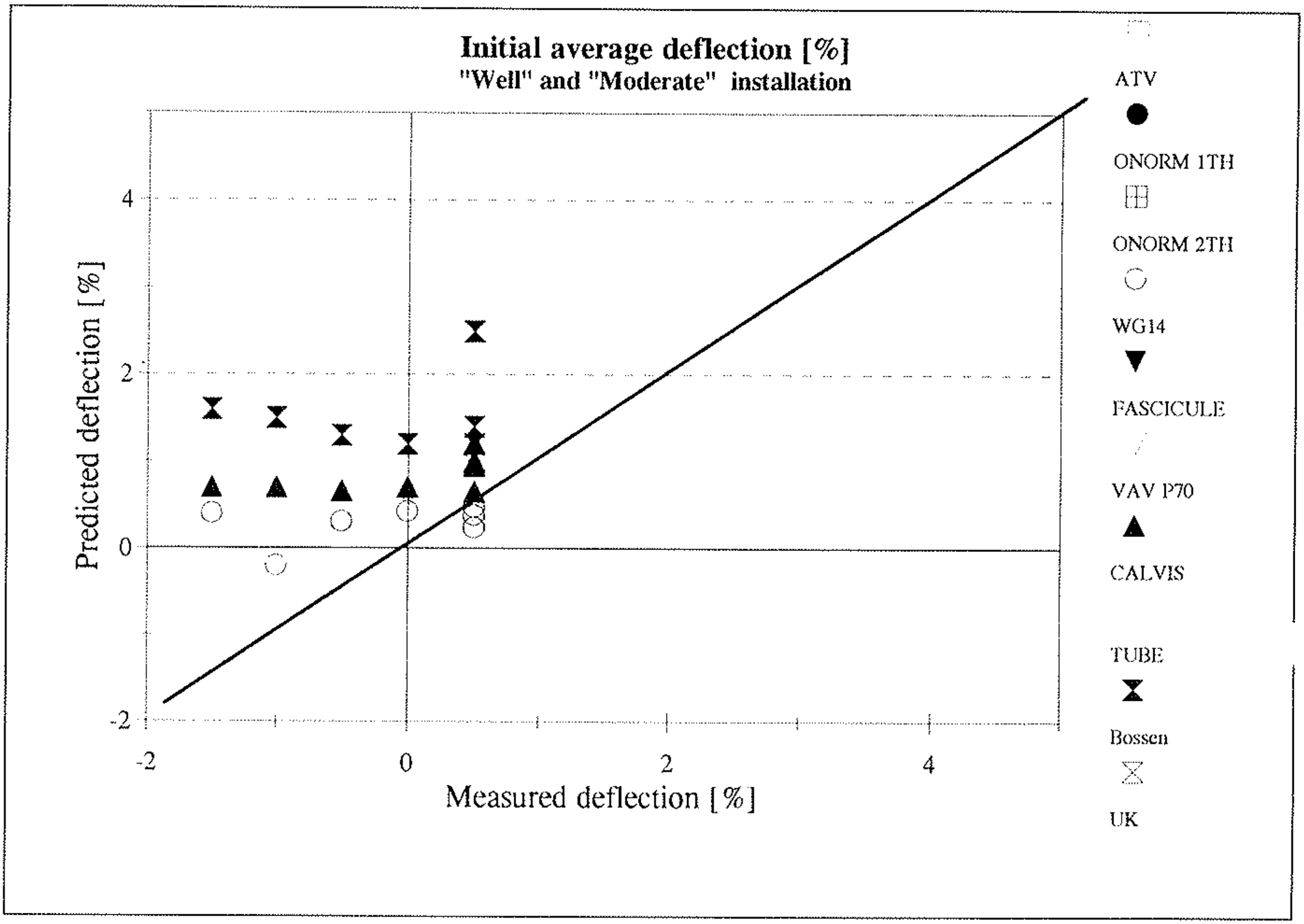
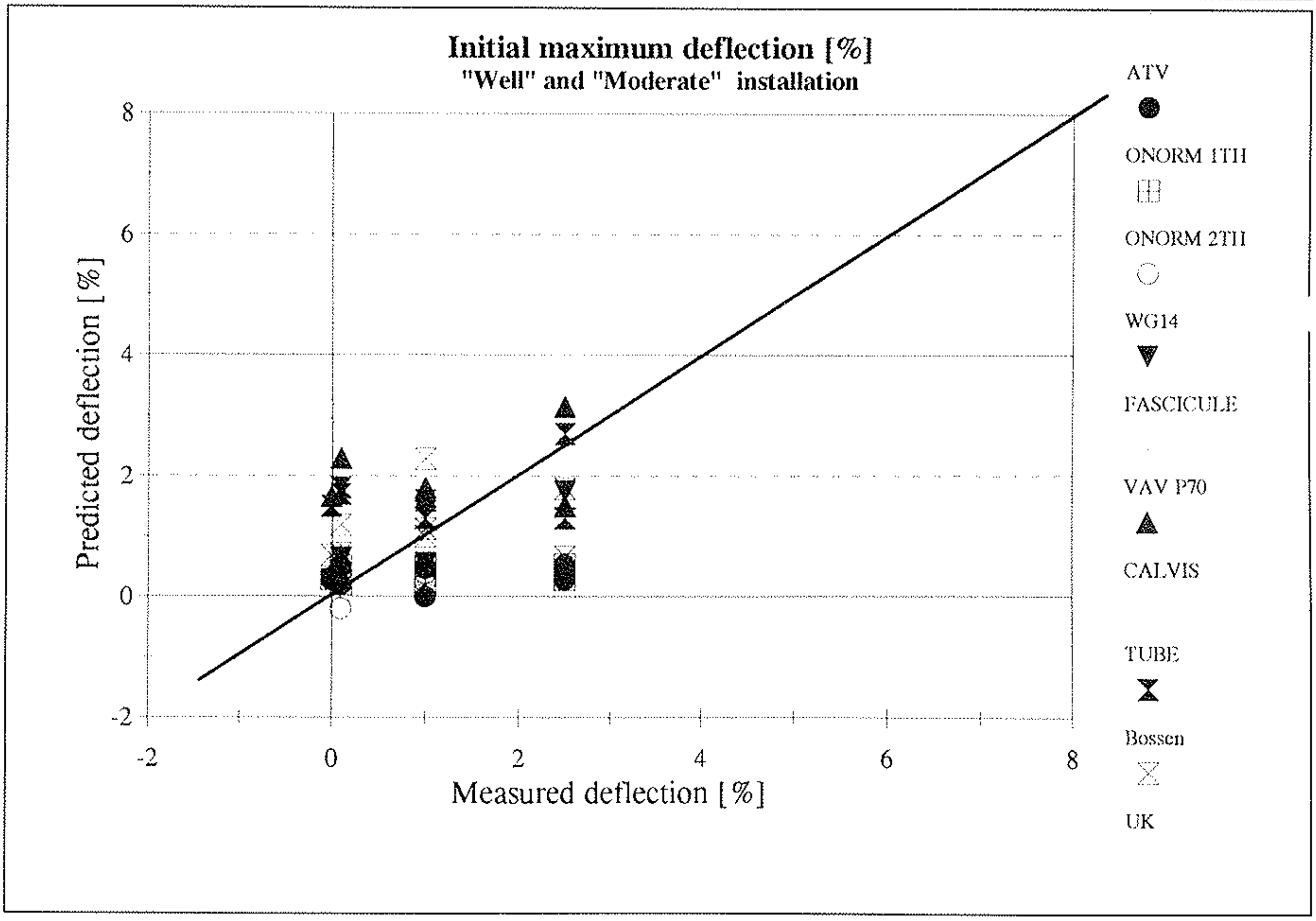
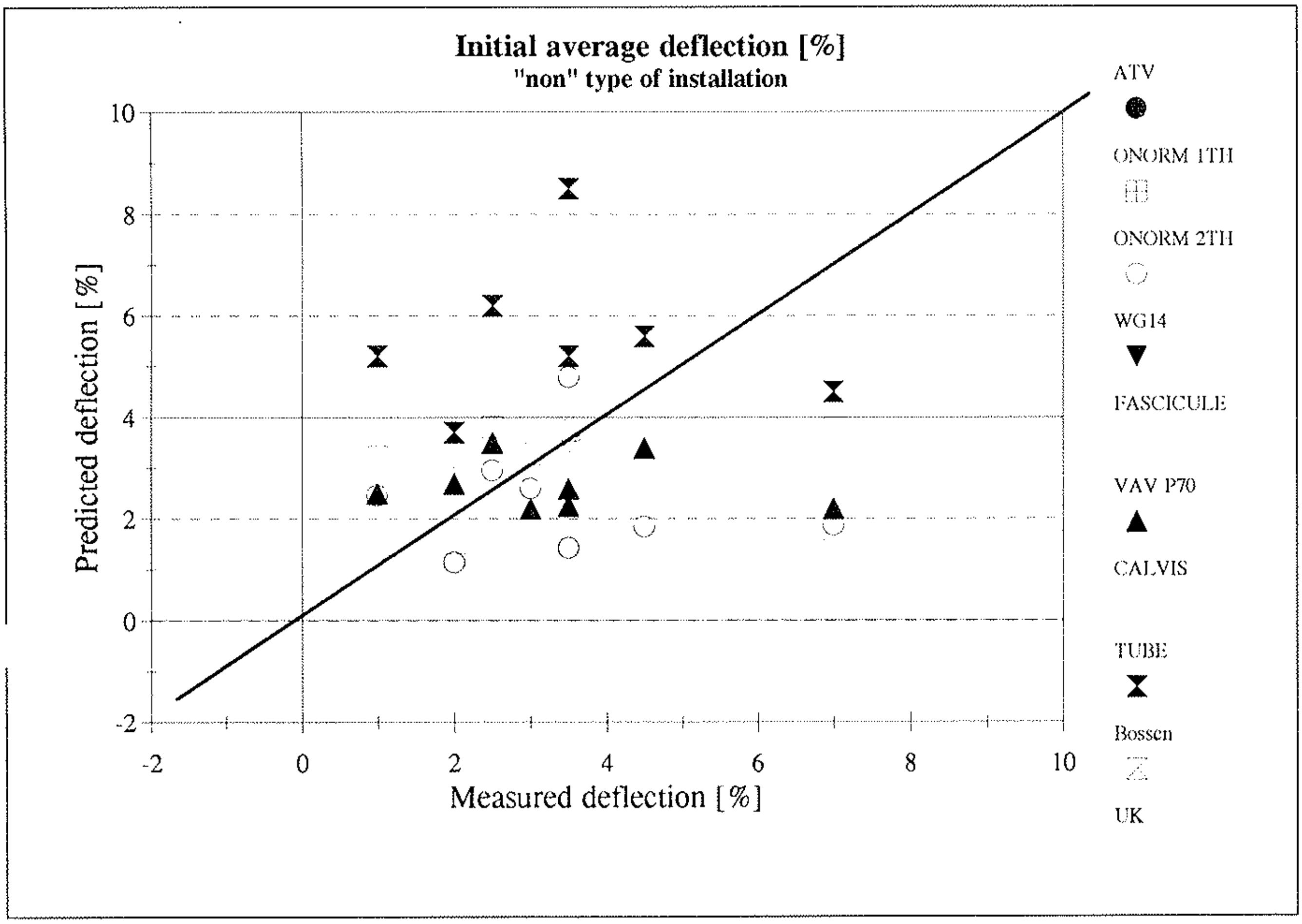
ENCLOSURE 1: Comparison between measured and first calculated results



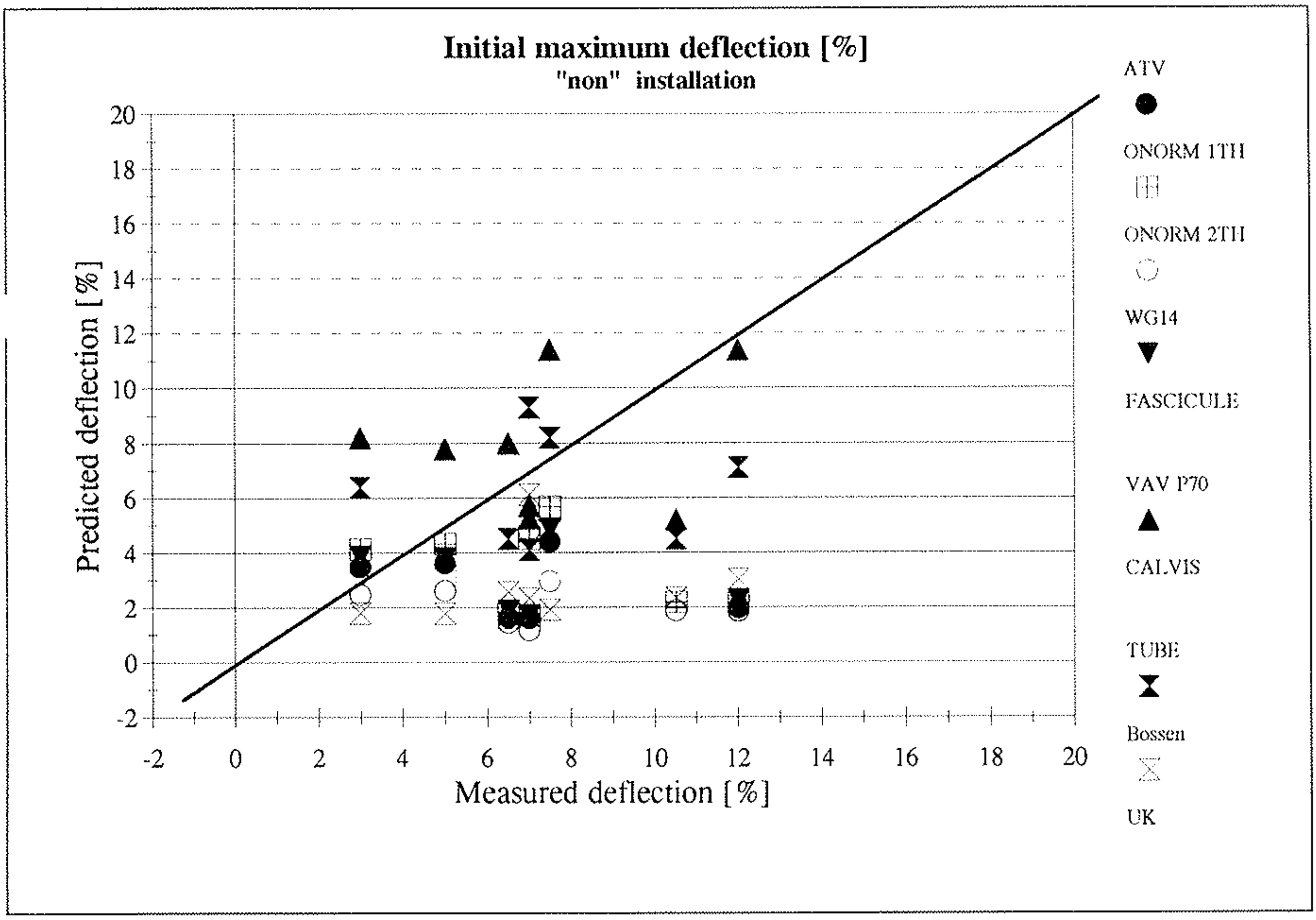


ENCLOSURE 2: Comparison between measured and first calculated results



Initial average deflection [%]

"non" type of installation



Initial maximum deflection [%]

"non" installation