UNIVERSITI PUTRA MALAYSIA

FINITE ELEMENT ANALYSIS OF ELASTOMERIC PUSH FIT SPIGOT AND SOCKET STEEL PIPE JOINT

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By

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Thesis Submitted in Fulfilment of the Requirement for the Degree of Master of Science in the Faculty of Engineering Universiti Putra Malaysia

December 2000

Very groteful to ALLAH for
the blessing…
To my family and everyone
involved in my life,
Thank you...

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science.

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Chairman: Megat Mohammad Hamdan Megat Ahmad, Ph.D

Faculty: Engineering

Pipe is the most important medium, which supplied water from one place to another. For places, which are far from the reservoir, the pipes must be joined in order to get water supply. A good pipe joint technique or method can reduce the non -revenue water. Spigot and socket push -- fit joint is one of the methods, which can be used for this purpose. This technique were mostly used for small diameter pipe but has not been introduced for steel main pipe. With the co-operation from BOON & CHEAH STEEL PIPES SDN. BHD. company, a project has been developed to analyse the ability of the joint for 600mm steel pipes.

Finite element method was used to analyse the ability of this joint. Two types of finite element software were used namely, LS-DYNA3D and LUSAS13. Both software have different processing system but they have the ability to analyse rubber material. Elastomer, which was used in this study, used Mooney-Rivlin strain energy equation.

There were another two methods involved, theoretical and experimental methods, to support the finite element analysis of the joint. LS-DYNA3D software was used for the 2 dimensional plane stress and axisymmetry elastomer using compression method to determine the pressure distributions at the top and bottom surface of the elastomer. Changes of the elastomer thickness and width (t and h) values have been made for the plane elastomer to identify the suitable pressure distribution, which can withstand the water pressure in the pipe. As for the analysis using LUSAS13, the 2 dimensional axisymmetry elastomer was being pushed to determine the pushing force, which can be used for the pipe connection.

From the theoretical, experimental and finite element analysis, it has been identified that the maximum pressure value at the top surface of the elastomer is higher than the water pressure in the pipe. The best pressure distribution developed was at t = 3 mm and h = 0.5 l mm. For the pushing force analysis, it is identified that to fit the joint, the pushing force must exceed 10 kN.

From the result, it is shown that the joint method can be used for large size steel pipe because the pressure value developed was higher than the internal water pressure. For the ease of joining, it has also been identified that the pushing force must be higher than the shear stress produced by the elastomer. Some recommendations has been proposed to get the most benefit of the analysis.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains.

ANALISIS SAMBUNGAN BERELASTOMER SPIGOT DAN SOKET JENIS KELULI MENGGUNAKAN KAEDAH UNSUR TERHINGGA.

Oleh

NURAINI BINTI ABDUL AZIZ

Disember 2000

Pengerusi: **Megat Mohammad Hamdan Megat Ahmad, Ph.D**

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Paip merupakan media penting dalam menyalurkan air dari satu tempat ke tempat yang lain. Penyambungan paip adalah perlu terutama untuk kawasan yang jauh dari sumber air. Teknik penyambungan yang baik dapat mengurangkan kadar pembaziran air. Salah satu teknik atau kaedah yang digunakan adalah menggunakan kaedah spigot dan soket. Kaedah ini sering digunakan bagi penyambungan paip berdiameter kecil tetapi belum pernah digunakan untuk menyambungkan paip keluli yang digunakan sebagai saluran utama. Dengan kerjasama syarikat BOON & CHEAH STEEL PIPES SDN. BHD., satu projek telah dijalankan untuk mengkaji keupayaan sambungan ini bagi paip keluli berdiameter 600mm.

Kaedah yang digunakan untuk mengkaji keupayaan sambungan ini adalah kaedah unsur terhingga. Dua buah perisian komputer iaitu LS-DYNA3D dan LUSAS13 telah digunakan bagi tujuan tersebut. Kedua – dua perisian mempunyai sistem pemprosesan yang berbeza tetapi mempunyai persamaan dalam menganalisa bahan yang diperbuat dari getah. Elastomer yang dianalisa menggunakan persamaan tenaga terikan Mooney-Rivlin. Dua kaedah lain turut dijalankan iaitu kaedah teori dan eksperimen bagi memastikan keberkesanan kaedah unsur terhingga.

Perisian LS-DYNA3D digunakan bagi menganalisa tegasan elastomer 2 dimensi berpermukaan datar dan berpaksi simetri dengan memampatkannya untuk mendapatkan taburan tekanan dibahagian permukaan atas dan bawah elastomer. Bagi elastomer berpermukaan datar, nilai ketebalan dan lebar (t dan h) telah dilakukan dengan tujuan untuk mendapatkan taburan tekanan yang sesuai bagi menampung tekanan dalaman yang terhasil dari air yang mengalir dalam paip. Bagi analisis menggunakan LUSAS13, elastomer berpaksi simetri 2 dimensi dikenakan daya tolakan bagi mendapatkan daya yang diperlukan untuk pemasangan paip.

Daripada teori, eksperimen dan analisis unsur terhingga yang dijalankan didapati bahawa nilai tekanan di permukaan atas elastomer adalah lebih tinggi berbanding tekanan air melalui paip. Bagi t = 3mm dan h = 0.5 l mm, didapati ia mempunyai taburan tekanan yang sekata. Bagi analisis terakhir didapati daya tolakan yang diperlukan bagi memasang sambungan paip tersebut mestilah melebihi 10 kN.

Daripada analisis, menunjukkan sambungan tersebut boleh digunakan sebagai salah satu kaedah penyambungan paip keluli berdiameter besar. Ini memandangkan nilai tekanan permukaan elastomer yang terhasil dari mampatan melebihi kadar tekanan air. Bagi memasang sambungan ini, daya tolakan perlu melebihi daya terikan yang dihasilkan oleh elastomer. Walau bagaimanapun masih terdapat beberapa cadangan yang diusulkan bagi mendapatkan hasil analisis yang lebih baik.

ACKNOWLEDGEMENTS

In the Name of ALLAH, The All Mighty.

I would like to send my graceful to ALLAH for the blessing and guidance. Special thanks and gratitude to Associate Professor Ir. Dr. Barkawi Sahari for his continuous support and guidance throughout the study. Also not forgotten to the co-supervisor Dr. Yousif A. Khalid and Associate Professor Dr. Azni Idris for their co-operation. I would also like to express my sincere gratitude to BOON & CHEAH STEEL PIPES SDN. BHD. for their supports. Also to Malaysian Rubber Board for notes and specifications. To all technical staffs and friends in Mechanical and Manufacturing Engineering Department for their supports.

To my family, thank you very much for your understanding.

This thesis submitted to the Senate of Universiti Putra Malaysia has been accepted as fulfilment of the requirement for the degree of Master of Science.

KAMIS AWANG, Ph.D,
Associate Professor,
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Date:

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LIST OF ABBREVIATIONS

a	Safety factor
b	Contact width
$C_{1,2}$	Elastic constant
d	Compression between spigot and socket
D	Original cross-section area
D_i	Internal diameter
D_o	Outer diameter
e	Joint factors
E_o	Young's Modulus
F'	Force per unit length
F_F	Frictional force
F_p	Axial force due to fluid pressure
G	Modulus of rigidity or shear modulus
$I_{1,2,3}$	Strain invariants
k	Boltzmann constant
K	Bulk Modulus
l	length
l_p	Pipe length
N	Number of chains per unit volume of the network
P_{ac}	Average contact pressure
P_f	Fluid pressure
P_i	Internal pressure

P_{max}	Maximum pressure
s	Shape function
S	Squeeze
t_o	width of elastomer back
t_p	Pipe thickness
T	Absolute temperature
T_g	Glass transition temperature
W	Strain energy
W_F	Load
W_l	Load per unit length
x	Compressive deformation
δ	Normalized squeeze
ε	Direct strain
λ	Extension ratio
γ	Shear strain
σ	Stress
$\sigma_{1,2,3}$	Principal stress
σ_c	Compression stress
$\sigma'_{c\,max}$	Maximum contact stress
$\sigma_{s\,min}$	Minimum steel stress
τ or t_{xy}	Shear stress
υ	Poisson's ratio

GLOSSARY OF TERMS

BS	British Standards
CMM	Coordinate Measuring Machine
FEA	Finite Element Analysis
FEMB	Finite Element Model Builder
IRHD	International Rubber Hardness
ML	Mooney's viscosity measurement
MRB	Malaysian Rubber Board
MWA	Malaysian Water Association
NRW	Non Revenue Water
PWD	Public Water Department
SBR	Styrene Butadiene Rubber
Catalysts	Specialized something that makes a chemical reaction happen more quickly without itself being changed.
Copolymer	Alloy like results of polymerisation of an intimate solution of different types of monomers.
Curing	An irreversible process during, which a rubber compound through a change in its chemical structure i.e. cross-linking, becomes less plastic and more resistant to swelling by organic liquids while elastic properties are conferred, improved, or extended over a greater range of temperature.
Filler	Relatively inert additive for a polymer, providing dimensional stability and reduced cost.
Monomer	Individual molecule that combines with similar molecules to form a polymeric molecule.

Synthetic rubber	Any of several substances similar to natural rubber in properties and uses, produced by the polymerisation of an unsaturated hydrocarbon, as butylenes or isoprene, or by the copolymerisation of such hydrocarbons with styrene, butadiene or the like.

CHAPTER 1

INTRODUCTION

Water is one of the basic necessities in life. It is therefore important to provide a proper distribution system. In Malaysia, public water supply in terms of water quality, quantity and reliability on the whole is satisfactory. The water supply sector in Malaysia has been growing rapidly at a rate over 9% per year over the last decade [23], which include that non revenue water or NRW. NRW is the amount of water put into the supply systems that bring no revenue to the water supply authority concerned and the NRW components are leakage through pipes, consumer meters under registration and other minor losses [49].

In most states, NRW is relatively high, ranging from 20% to 60% with a national average of 43% [23]. In 1978 it was 26%, 1983 it was 32% and 1996 up to 38% [23]. Efforts are being carried out to keep this within an acceptable limit, which is within 25% and this has been a long-term objective planned by the Federal Government by the year 2000 [49]. As mentioned above, leakage is one of the factors, which contributes to NRW. Leakage happens if there is a crack on the pipe or due to poor joining system. Pressure, temperature and soil movements were among the factors that could cause leakage. This condition can affect the efficiency of water distribution and piping system.

There are several types of pipe materials and joining system applicable with different sizes used [50]. Pipe materials such as asbestos-cement with sizes from 100 to 600 mm diameter have been extensively used. The large size pipe for the mains supply are usually made steel, grey cast iron or ductile iron [50]. These pipes could be joint using different types of joining system such as flanged joint, welded joint, flexible mechanical coupling, push-on spigot and socket to supply water especially to rural areas. In this project a push-fit elastomeric spigot and socket steel pipe is used.

These push – fit elastomeric spigot and socket joint for steel pipe is introduced by BOON & CHEAH STEEL PIPE SDN. BHD. as an alternative joining system for steel pipelines because this method can ease the job of pipes joining and reduce the installation cost. However, for steel pipe especially large diameter pipes used for water distribution, this push-fit method has not been widely used. This is due to the scarcity of the design data for such component.

As such a lot of research work on the capability of manufacturing and the strength of this joint to withstand pressure, temperature which cause leakage problem need to be carried out. The push-fit elastomeric spigot and socket supplied by BOON & CHEAH STEEL PIPE SDN. BHD. will be studied and analysed. Different parameters, which affect the design and the performance of the joint, will be investigated. The finite element method will be used together with LS-DYNA3D and LUSAS13 software package.

LUSAS13 and LS-DYNA3D are a PC based software and is able to analyse two and three dimensional model and simulation respectively. This study includes compressible elastomeric rings used as pipe seals. The main steps required in this investigation are the construction of finite element model and mesh for the pipes and elastomer. Then the next step is to input the materials, properties, boundary conditions and it's interfaces of each part. Different designs and material changes have been made to identify the suitable parameters, which affect the performance of the elastomeric rings.

The objectives of the project are:

1. To determine the design parameter that affects the pressure distribution of integral elastomeric seal for the spigot and socket joint in steel pipes.
2. To determine the leaking criteria of integral spigot and socket joint when subjected to steady internal pressure.
3. To determine suitable design parameters and joint capacity.

This project report consists of seven (7) chapters including the introduction. The second chapter will be on the review of literature related to this project. The literature review will also cover the main theories and experiments done by researches on pipes and elastomers including their properties and applications. Chapter two includes a collection of the most different types of piping systems including the one used in this study.

Chapter 3 covers the materials and methods of the research project. Chapter 4 presents the results while chapter 5 will include the discussion of the research carried out. Chapter 6 will conclude the project findings and Chapter 7 will include the recommendations for future works, which can upgrade the present design of push-fit elastomeric spigot and socket for the steel pipes.

CHAPTER 2

LITERATURE REVIEW

In this chapter, the literature related to pipe joints and seal are reviewed. Attention is focused on elastomeric or rubber seal mechanisms and their theoretical work. Finite element software, LS-DYNA3D and LUSAS13 are also being reviewed. Throughout this chapter, studies carried out for the joining system using different types of elastomer will be focussed. Further discussion on the properties of the elastomeric ring was also being done. An overview of pipe materials especially steel pipeline will be considered further including a topic on their properties. Discussions would also be carried out on the types of push-fit joints used for different pipes. In problem definition section, descriptions of the push fit method as shown in Figure 2.1, would be done. This will include the spigot/socket, elastomeric and sealing mechanism.

2.1 Elastomeric Ring Seal

Elastomers are widely used in industry as sealant materials, load-bearing materials, and cushion materials. Many investigations [17, 25, 32, 34, and 35] were carried out on different elastomer seal type. Elastomers are considered to be isotropic, highly deformable, highly elastic, and nearly incompressible [35]. Elastomeric sealing rings, especially in the form of O-rings, are used in numerous applications [25].

Elastomer seals are usually formed as a circular ring of various cross-sectional configurations in a gland to close off a passageway and prevent escape or loss of a fluid or gas. Designing for an elastomeric ring seals depends on three major and interrelated variables; namely, the operating conditions or environment the seal will experience, the gland geometry into which the seal will be installed and the seal material and geometry [32].

2.1.1 Elastomer Properties

In this section, the properties of the elastomer will be discussed. It will be studied and used in designing the elastomeric joint. The most known properties are the ability to support large elastic strains. Some elastomer are capable of sustaining tensile elongation's of the order of 1000% from which they can recover their original dimensions almost completely [40]. The polymerised chain –like molecules structure gave the elastic characteristic of the rubber or elastomer and this depends on the temperatures, forces and pressure factors.

2.1.1.1 Stress-Strain Behaviour

The stress strain properties have been studied by several researches [6, 12, 15, and 26]. The mechanism of rubber-like deformation makes it possible to predict the shape of the stress-strain curve for rubber in either tension or compression [6]. For uniaxial tension and compression the stress strain relation is given as Equation 2-1.

$$\sigma = G\left(\lambda - \lambda^{-2}\right) \qquad \textbf{Eqn. 2.1}$$

where

σ = Stress of the original undeformed cross-section

G = shear modulus or modulus of rigidity

λ = ratio of extension to unstrained length.

The comparison between Equation 2.1 with the experimental behaviour is shown in Figure 2.2. The Figure shows that Equation 2.1 compared with the experimental results for $\lambda < 0.4$. The essential point to note is that the slope of the rubber stress-strain curve (i.e. tangent modulus) increases with the deformation increase, so that it is not easy to define the elastic behaviour of rubber simply by Young's modulus like steel [6]. However, rubber rarely used in an engineering situation at tensile strains greater than 100%, and good correspondence is shown in the more important compressive region [12].

2.1.1.2 Time and Temperature Effects

The work on the affect of time and temperature on the rubber is carried out by several investigations [2, 3, 4 and 13]. The common basis of rubbers and plastics is the underlying structural concept of small chemical repeat units (the monomeric units), which have been polymerised to form chain-like molecules. These molecules would give the rubbers and plastics their elastic characteristics.

As mentioned above, the elastic behaviour can vary according to the temperatures, forces, and pressure. If the environmental temperature is high, the molecule become flexible which lay the foundation for a large-strain elasticity characteristic of rubbers. As the temperature is reduced, the flexibility of the molecules decrease and the material become stiffer. Figure 2.3 shows the relationship between the modulus of rubber and temperature/strain rate.

The transition from the rubber-like to the glassy state is a phenomenon, which is encountered in all rubbers, whether vulcanised or unvulcanised, though the temperature at which this transition occurs naturally depends on the chemical composition of the molecule. These transitions are accompanied by changes in certain other physical properties in addition to the changes in elastic properties.