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# Optimum Design of a Capsule Shaped Proving Ring with Variable Rectangular Cross Section having a Load Measuring Capacity of 250 Tonnes

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## Abstract

This study analyzes the optimum design of a capsule shaped proving ring with variable rectangular cross section analytically followed by the numerical approach for validating the analytical results of the optimum design. The proving ring is designed to measure loads up to 250 tonnes. The maximum allowable stress is governed by the elastic limit of the material of the proving ring. The size (radius, length, width and thickness) of the proving ring is calculated in analytical approach. Locally available structural steel is selected as the material of this investigated structure. The diametral deflections of the proving ring for different applied loads are calculated using Castigliano's theorem. To perform all these analytical calculations, several computer programs are developed using MATLAB software. After finding the optimum design, the actual 3D model of the capsule shaped proving ring is developed using Solidworks software. To validate the analytical results, the designed capsule shaped proving ring is also investigated numerically using Ansys as the simulation software that uses finite element method. Finally, a compressive load vs diametral deflection plot is generated to observe the variations of diametral deflections of the designed proving ring for different applied loads within the design limit (0 to 250 tonnes).

## Keywords
Proving ring, Capsule shape, Optimum Design, Elastic deflection and Finite element method.

## 1. Introduction
Proving ring is a very well-known load measuring instrument. It changes its shape when load is applied on it. An elastic diametral deflection occurs in proving ring under loading condition. Observing this deflection, the amount of applied load is found easily from load-deflection plot for that respective proving ring. This load measuring instrument has many usages in structural or mechanical laboratories and industries. It serves purposes like measuring loads in different machines or calibrating different other load measuring devices like universal testing machines, load cells, hydraulic presses etc. So, as there are so many types of these load measuring devices of different capacities, different proving rings of different shapes and capacities are being used worldwide. So, the design of this widely used load measuring instrument consistently is being updated and modified with needs and requirements of particular machines where a proving ring is needed to measure the load or calibrate the machine. Designing such kind of instrument for manufacturing locally with local materials can contribute to the local advancements in engineering and research sectors of any country.

### 1.1 Literature Review
With advancements of engineering and technology, different studies are conducted on load applied ring structures and proving rings over time. Many old and recent investigations are found on proving rings of different sizes, shapes, materials and cross sections. Reid and Bell (1982) have investigated the effects of strain hardening on the deformation of thin rings subjected to opposed concentrated loads. They found a significant load deflection characteristic using their investigated framework. O'Dogherty (1996) worked on the design of the octagonal ring dynamometer where the fundamental formulae for the moment and strain distributions were presented along with the design equations of the ring and the expressions to calculate the deflections and stiffnesses. Sever researches are done on beams having variable cross sections and uniform strength. Rahman et al. (2006) have studied the Large deflection of the cantilever steel beams of uniform strength. Later nonlinear analysis of cantilever shape memory alloy beams of variable cross-section is studied by Rahman and Kowser (2007). Timoshenko (1941) derived the mathematical equations for

different curved beams of different shapes. Budynas and Nisbett (2013) wrote a detailed book that includes design procedures and equations for different curved machine elements. These studies are similar and directly related to the studies on proving rings. Rahman et al. (2004) worked on the optimum design of a proving ring. Rahman et al. (2004) investigated on the optimum design of a circular proving ring with variable rectangular cross sections. They used different discrete rectangular segments of different constant thicknesses instead of varying the thickness continuously. They manufactured a circular proving ring of variable cross section with load measuring capacity of 5 ton and compared experimental results with theoretical results. Rahman and Rahman (2005) studied the design parameters of circular proving ring of uniform strength. They focused on designing proving ring for different load measuring capacity keeping a constant strength throughout the structure. So, several studies are done already on designing proving rings. There are some note on designing and manufacturing proving rings with constant cross sections in the website of National Institute of Standard and Technology (2003). These studies show the pathway for designing and manufacturing circular proving ring with both constant and variable cross sections.

### 1.2 Objectives

It is found that no study is conducted yet to find the optimum design of a capsule shaped proving ring with variable rectangular cross section that can measure a huge amount of load like 250 tonnes. Such a larger proving ring is required to calibrate a universal testing machine that can generate load of around 250 tonnes. As per authors' knowledge, there are lack of numerical studies on designing any proving ring too. So, the aim of this present study is to analytically find the optimum design of a capsule shaped proving ring with variable rectangular cross section that can measure up to 250 tonnes of load and numerically validate the analytical design to ensure the legitimacy of the analytical design so that this proving ring can be practically manufactured in Bangladesh with locally available materials and manufacturing facilities. Developing a MATLAB based computer program for analytical calculations, developing the actual 3D model of the proving ring using Solidworks, numerical simulation of the developed model to validate analytical results using Ansys and generating related plots along with developing the compressive load vs deflection plot for the proving ring are also some of the notable objectives of this study to perform the design procedure.

## 2. Mathematical Modeling

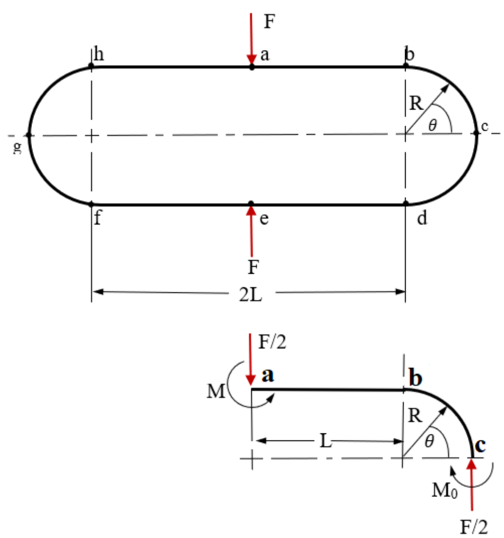



**Figure 1.** Free body diagram of diametrically loaded capsule shaped ring

Figure 1 depicts the free body diagram of a capsule shaped ring. As the design of a capsule shaped proving ring is conducted in this study, all the moment, stress and deflection analysis are done using the free body diagram from Figure 1. The structure of the capsule shaped ring contains both linear (*hb* and *fd*) and curved (*bcd* and *fgh*) portions. Here, the length of the linear portion is $2L$ and the radius of the curved portion is $R$. A load, $F$ is applied at the middle of the linear portion of the ring. This load is responsible for the bending moment, $M$ at any section of the ring and the statically indeterminate moment, $M_0$.

Here, the bending moment at the linear portion, $M_l$ and the bending moment at the curved portion, $M_c$ are found by the following Equations (1-2) derived using mechanics,

$$M_l = M_0 - \frac{F}{2}(x + R) \tag{1}$$

$$M_c = M_0 - \frac{FR}{2}(1 - cos\theta) \tag{2}$$

Here, $0 \leq x \leq L$ and $0 \leq \theta \leq \pi/2$. The statically indeterminate moment, $M_0$ for a capsule shaped ring is determined by following Equation (3),

$$M_0 = \frac{F}{2}\left(\frac{L^2+2RL+\pi R^2+2R^2}{2L+\pi R}\right) \tag{3}$$

The elastic diametral deflection of the capsule shaped ring according to the free body diagram (Figure 1) is calculated solving the following Equation (4) found using Castigliano's theorem,

$$\delta = 4\frac{\partial}{\partial F}\left[\int_0^L \frac{M_l^2}{2EI_l}dx + \int_0^{\pi/2} \frac{M_c^2}{2EI_c}Rd\theta\right] \tag{4}$$

Here, $E$ is the Young's modulus of the material and $I_l$ *and* $I_c$ are the area moment of inertia of the linear and the curved portion respectively. To calculate the diametral deflections and the combined stresses at any portion of the ring, the effects of shear stress are assumed negligible. The stress at the linear portion, $\sigma_l$ is calculated using straight beam formula and the curved beam formula is used to calculate the combined stresses at curved portion, $\sigma_c$. These stresses are calculated using the following Equations (5-7),

$$\sigma_l = \frac{M_l H_l}{2I_l} \tag{5}$$

$$\sigma_{c,o} = \frac{MC_o}{AeR_o} - \frac{Fcos\theta}{2A} \tag{6}$$

$$\sigma_{c,i} = -\frac{MC_i}{AeR_i} - \frac{Fcos\theta}{2A} \tag{7}$$

Here,

$H_l$ = Thickness of the ring at any position in linear portion
$H_c$ = Thickness of the ring at any position in curved portion
$\sigma_{c,o}$ = Combined stress at the outer surface of the curved portion
$\sigma_{c,i}$ = Combined stress at the inner surface of the curved portion
$R_o = R + \frac{H_c}{2}$ = Distance between the outer surface of the curved portion and the center of the curvature
$R_i = R - \frac{H_c}{2}$ = Distance between the inner surface of the curved portion and the center of the curvature
$R_n = \frac{H_c}{\ln\left(\frac{R_o}{R_i}\right)}$ (for rectangular cross section) = Distance between the neutral axis and the center of the curvature
$C_o = R_o - R_n$ = Distance between the neutral axis and the outer surface
$C_i = R_n - R_i$ = Distance between the neutral axis and the inner surface
$e = R - R_n$ = Distance between the neutral axis and the radius of curvature
$A$ = Area of the cross section

## 3. Design Methodology

### 3.1 Analytical Design Procedure

In this study, a capsule shaped proving ring with variable rectangular cross section in designed for load measuring capacity of 250 tonnes. This proving ring is designed specially so that it can be used for calibrating the universal compression testing machine at the solid mechanics laboratory of the Department of Mechanical Engineering at

Bangladesh University of Engineering and Technology (BUET). So, it is designed keeping the dimensions of the stated universal compression testing machine in mind. This proving ring can be used in other machines with such dimensions too.

The proving ring is designed keeping the safety factor around 2. The maximum allowable stress at any portion of the proving ring is considered 200 MPa. This stress is kept constant along the linear portion of the proving ring and this stress is considered as the maximum stress at the curved portion. Variable rectangular cross section is used to serve this purpose. Variable cross section not only keeps the stress constant, it also increases the sensitivity of the proving ring which is found from some previous studies (Rahman et al., 2004, Rahman and Rahmn, 2005). Locally available structural steel with a Young's modulus of 200 GPa and yield strength of around 400 to 450 MPa is considered as the material of the proving ring while designing the capsule shaped ring with variable rectangular cross section. Considering shear stress effects negligible, the width of the proving ring, $W$ and the thicknesses of the proving ring ($H_l$ and $H_c$) are calculated using stress analysis at different portions of the ring assuming different values of $L$ and $R$ within the design conditions through different trials. The width is constant along the whole proving ring structure and only thicknesses are varied. The dimensions at the straight portion of the ring are found using straight beam formula by Equation (5). At the curved portion, combined stress is larger at the inner surface of the proving ring. So, Equation (7) is used to find the dimensions at the curved portion. To keep the stress constant at linear portion, maximum thickness at linear portion, $H_{l,\,max}$ is found at the middle of the linear portion (point *a* and *e* in Figure 1). The minimum thickness at linear portion, $H_{l,\,min}$ is found where the linear and the curved portions meet (point *b*, *d*, *f* and *h* in Figure 1) which is also considered as the minimum thickness of curved portion of the ring ($H_{c,\,min} = H_{l,\,min}$). The thicknesses at any position of the linear portion of the proving ring maintains linear relation automatically if the stress is considered constant at linear portion and can be found using the following relation,

$$H_l = H_{l,min} + \frac{H_{l,max} - H_{l,min}}{L} x \tag{8}$$

The maximum stress occurs at $\theta = 0°$ in curved portion which is the maximum allowable stress that is constant at linear portion. So, the maximum thickness at curved portion, $H_{c,\,max}$ is found at $\theta = 0°$. The thicknesses at other portions of the curved portion of the ring ($H_c$) is calculated using linear relation between $H_{c,\,max}$ and $H_{c,\,min}$ as the follows,

$$H_c = H_{c,max} - \frac{H_{c,max} - H_{c,min}}{90} \theta \tag{9}$$

The stress is not kept constant at the curved portion due to avoid complexity in designed model in further manufacturing operations. So, following this design procedure, the 2D front view of the proving ring structure for analytical calculations is depicted in Figure 2.

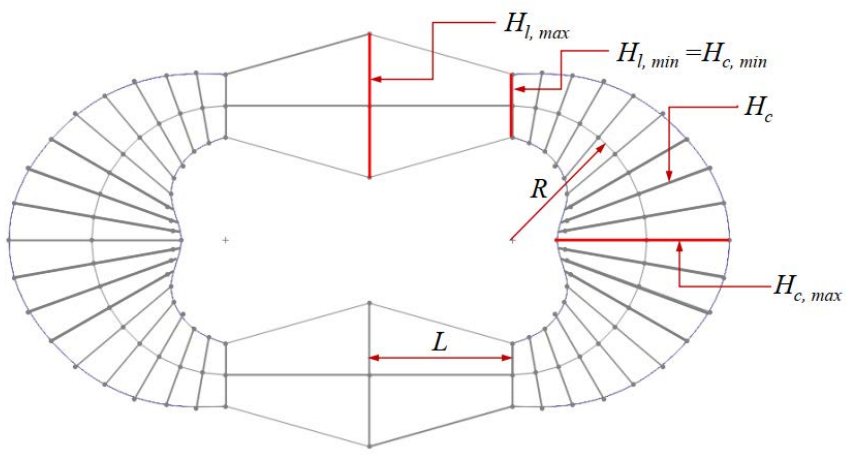



**Figure 2.** 2D front view of the basic structure of the proving ring for analytical design

### 3.2 Program Features

A MATLAB based computer program is developed to perform all the analytical calculations for stress and deflection analysis. The developed program can calculate moments, stresses, dimensions, deflections and all the necessary parameters for any capsule shaped proving ring with variable rectangular cross section. This program is so beneficial and time saving during assumptions and trials while designing any capsule shaped proving ring of any size and capacity. In this investigation, the optimum design of the proving ring is found analytically using this program for moderate size, sensitivity and constant maximum allowable stress (200 MPa). The deflections of the proving ring for different loads (up to 250 tonnes) are found also using this program solving Equation (4).

### 3.3 3D Modeling Procedure

The analytical calculations are done for designing the proving ring according to the structure illustrated in Figure 2 which is the basic structure of the proving ring. But any practical proving ring needs some extra accessories like dial indicator gauge, top attachments where the load will be applied and a base. So, these accessories need some mounting spaces in respective places of the proving ring. In Figure 3, the modified 2D front view of the basic structure of the proving ring is illustrated with necessary mounting spaces, fillets and simplified shape of curved portion so that it can be easily manufactured using local facilities. No dimension is reduced for this modification, so a little deviation in results is reasonable but that will not hamper the safety factor of the proving ring.

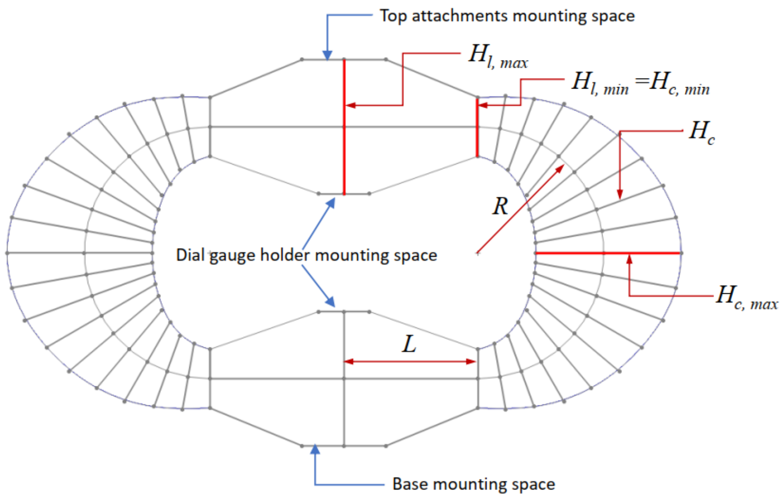



**Figure 3.** Modified 2D front view of the basic structure of the proving ring with necessary mounting spaces

After finding all necessary dimensions of the capsule shaped proving ring with a load measuring capacity of 250 tonnes, the actual 3D model of the designed capsule shaped proving ring is developed using a CAD software, Solidworks which is later used for the numerical validations of the analytically designed structure. The 3D isometric view of the actual model of the proving ring developed in Solidworks is illustrated in Figure 4.

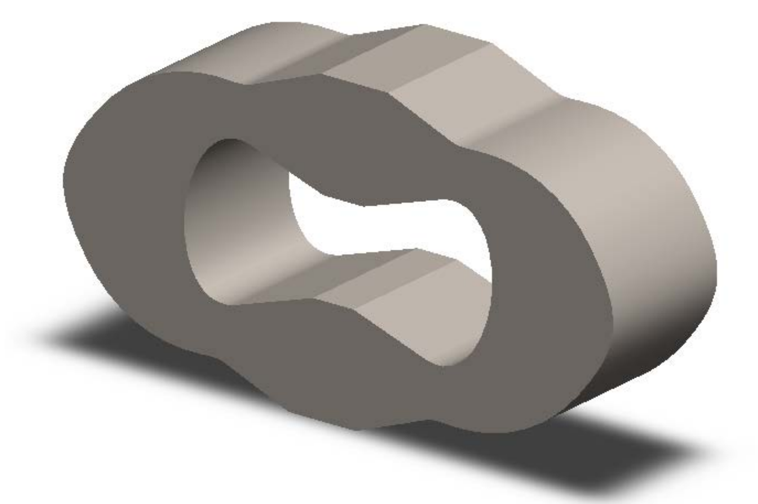


**Figure 4.** Isometric view of the developed 3D model of the actual capsule shaped proving ring

### 3.4 Simulation Procedure

All the design procedures along with the stress and deflection analysis of the proving ring are performed analytically. So, before manufacturing the proving ring, a numerical simulation of the developed actual 3D CAD model of the proving ring is needed as there are some assumptions and modifications used in the analytical calculations and the 3D modelling of the proving ring using CAD software in this study. To observe the results closer to the actual scenario of the stresses, safety factors, deflections in different portions of the designed proving ring, numerical simulation of the proving ring model developed in Solidworks is done with appropriate design material (structural steel) with design properties using ANSYS, a simulation software. Finite element method is used as the numerical method here in this software to perform the simulation procedure. Both quadrilateral and triangular mesh are applied on the structure for the simulation and total mesh element numbers used in this study is 30996. The mesh generation throughout the structure of the proving ring is depicted in Figure 5.

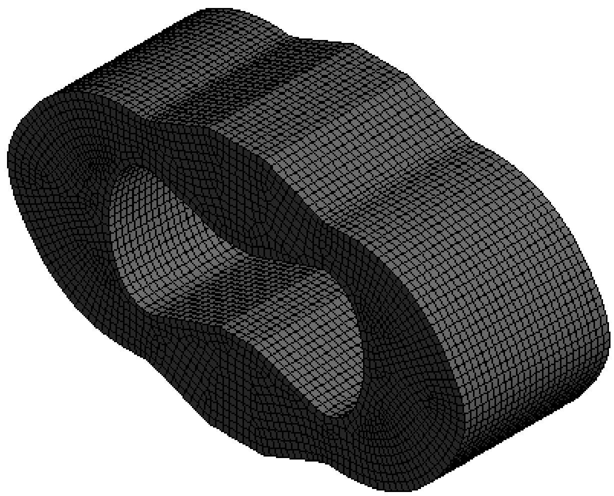


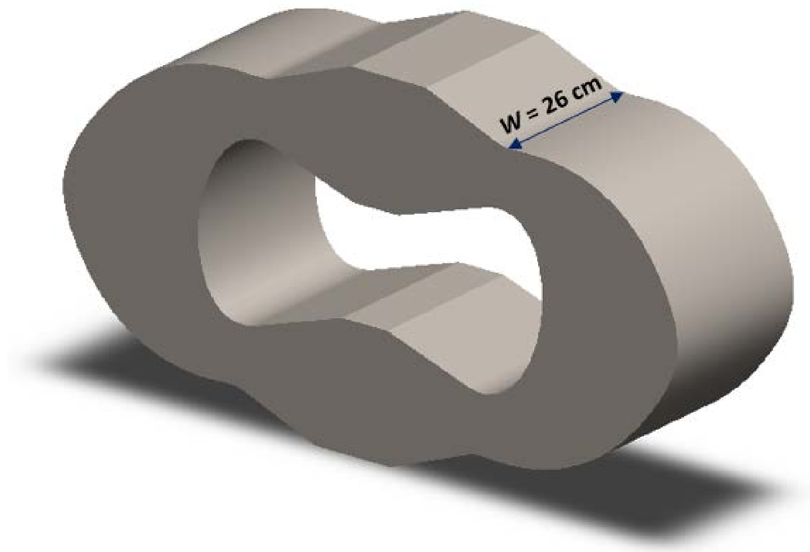
**Figure 5.** Mesh generation for simulation using ANSYS

## 4. Results and Discussions

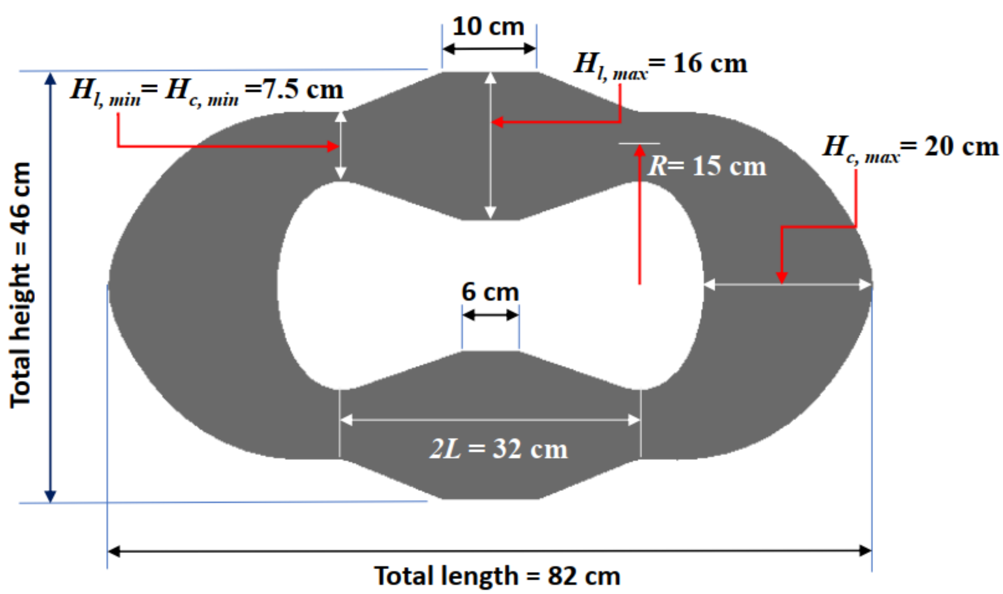
### 4.1 Analytical Results

A capsule shaped proving ring with variable rectangular cross section is designed in this study analytically so that it can measure large amount of loads up to 250 tonnes. As stated earlier, the maximum allowable stress across the proving ring is considered around 200 MPa with a safety factor around 2 for the analytical calculations. Locally available structural steel with Young's modulus, $E$ = 200 GPa is considered as the design material and its yield strength, $S_y$ should be within 400 MPa to 450 MPa for the desired safety factor. The total length, width and the total height of the proving ring should be limited within 90 cm, 40 cm and 60 cm respectively to make the proving ring compatible with the dimensions of the particular model of universal compression testing machine of the solid mechanics laboratory at the Department of Mechanical Engineering at Bangladesh University of Engineering and Technology (BUET). So, using the developed computer program, several trials are done assuming different values for $L$, $R$ and $W$ to calculate the thicknesses of the proving ring at its different portions and finally the optimum values of $L$, $R$, $W$, $H_{l, max}$, $H_{l, min}$, $H_{c, max}$ and thicknesses at different areas of curved portions, $H_c$ are found that satisfy all the design conditions stated above. The optimum values of these parameters are listed below,

- $2L$ = Length of the linear portion of the proving ring = 32 cm
- $R$ = Mean radius of the capsule shaped proving ring = 15 cm
- $W$ = Constant width of the proving ring = 26 cm
- $H_{l, max}$ = Maximum thickness at the linear portion of the proving ring = 16 cm
- $H_{l, min}$ = Minimum thickness at the linear portion of the proving ring = 7.5 cm
- $H_{c, min}$ = Minimum thickness at the curved portion of the proving ring = 7.5 cm
- $H_{c, max}$ = Maximum thickness at the curved portion of the proving ring = 20 cm




**(a)**




**(b)**

**Figure 6.** Optimum dimensions of the proving ring using (a) isometric view and (b) front view

This analytical design is based on the basic structure of the capsule shaped proving ring illustrated in Figure 2. In this design, the maximum allowable bending stress is kept constant at linear portion (200 MPa) but to avoid complexity in design and manufacturing the curved portion, the stress is not considered uniform at the curved portion. The thicknesses at different position at the curved portion of the proving ring are linearly varied between $H_{c,\,max}$ and $H_{c,\,min}$ and calculated using Equation (9) considering the maximum allowable stress 200 MPa at $\theta = 0°$. So, according to this analytical design, the combined stress in not uniform in the curved portion of the ring but the maximum combined stress is considered at the inner surface of the curved portion of the ring at $\theta = 0°$ and that is 200 MPa. The thicknesses at different position of the curved portion of the proving ring is stated in Table 1.

**Table 1**: Thicknesses at different angular positions of the curved portion of the proving ring

| Angular position ($\theta$) | 0° | 10° | 20° | 30° | 40° | 50° | 60° | 70° | 80° | 90° |
|---|---|---|---|---|---|---|---|---|---|---|
| Thickness ($H_c$) | 20 cm ($H_{c,\,max}$) | 18.5 cm | 17 cm | 16 cm | 14.5 cm | 13 cm | 11.5 cm | 10 cm | 9 cm | 7.5 cm ($H_{c,\,min}$) |

Using these analytically found optimum dimensions, a 3D model of the proving ring is developed using Solidworks. The optimum dimensions of the designed capsule shaped proving ring are shown in Figure 6 by the actual 3D CAD model of the proving ring.

### 4.2 Numerical Validation of the Analytical Design

During designing the proving ring analytically, some assumptions are considered and some measurements of different dimensions are taken as rounded up values. As mentioned earlier, the shear stress effects are neglected during the analytical design. The analytical calculations of different dimensions of the ring are based on Figure 2. But after some further modifications of the basic structure of the proving ring, our final design is based on Figure 3 having necessary mounting spaces and simplified curved portion of the proving ring. So, due to these assumptions and dimensional modifications, some deviations in stresses, safety factors and other parameters may occur. So, the final 3D model developed using software needs numerical validation to make sure whether the modified results are satisfied or not. Numerical simulation of the actual 3D CAD model of the proving ring is conducted using Ansys. To make sure that the structure does not fail while measuring 250 tonnes load, the actual stresses and safety factors developed across the proving ring needs to be observe. Numerical results for von Mises stress and safety factors at different portions of the designed 3D model of the capsule shaped proving ring is depicted in Figure 7 and Figure 8 respectively.

It is observed from Figure 7 that the stress developed in the surfaces of the linear portion of the proving ring is almost constant and close to around 200 MPa which matches our analytical design. But there are some deviations in the stresses developed in the curved portion of the proving ring. The equivalent von Mises stress at the outer surface of the proving ring is much lower that is expected. At the inner surface of the proving ring, the equivalent von Mises stress at $\theta = 0°$ is around 200 MPa that meets the analytical criteria nicely but near this portion, the equivalent von Mises stress higher than 200 MPa is developed in some area. This occurs because of the assumptions and modifications stated earlier. This slightly deviated results are not surprising as we counted the shear effects negligible and the final proving ring structure (Figure 3 and Figure 4) is slightly different from the initial basic structure (Figure 2) according to which the analytical calculations are done. Besides, in analytical design, 1D principle stress analysis is done but 3D von Mises stress is observed in numerical simulation. So, some deviations in results are not unexpected. In the design conditions, the safety factor was tried to keep around 2 analytically.

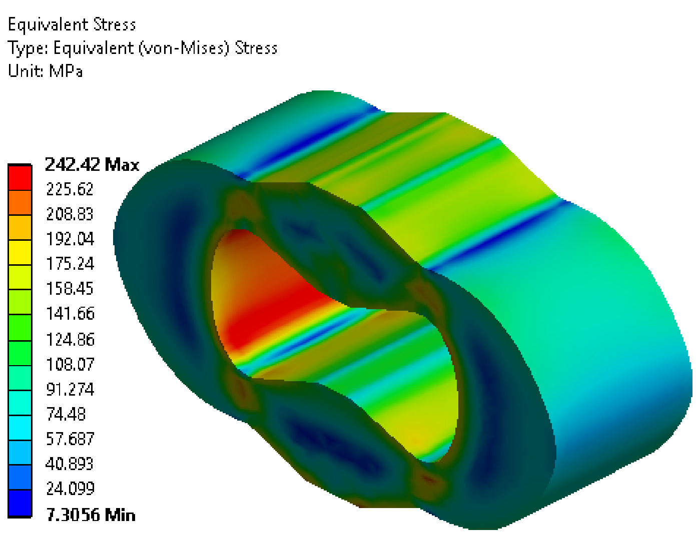


**Figure 7.** Numerical results for equivalent von Mises stress at different portions of the proving ring

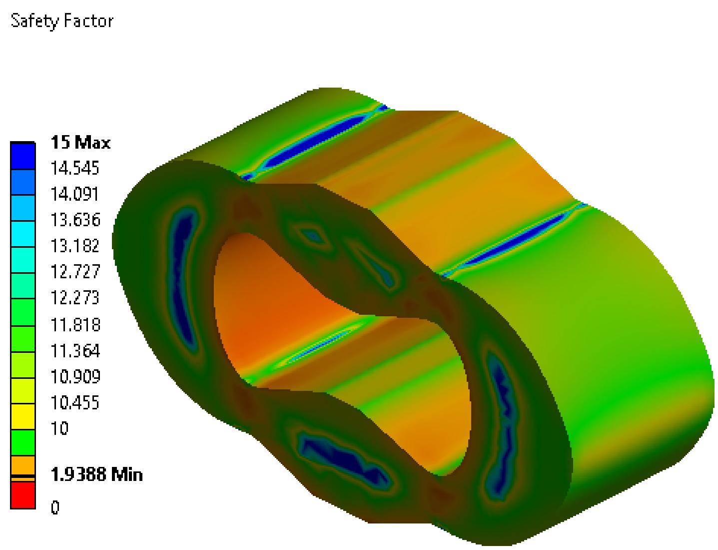



**Figure 8.** Numerical results for safety factor at different portions of the proving ring

In the simulation results, it is clear from Figure 8 that the lowest safety factor of the designed proving ring very close to 2 that is satisfactory. So, the simulation results prove that the analytical design quite satisfactory that it will not fail during load measuring operations.

## 4.3 Deflection analysis

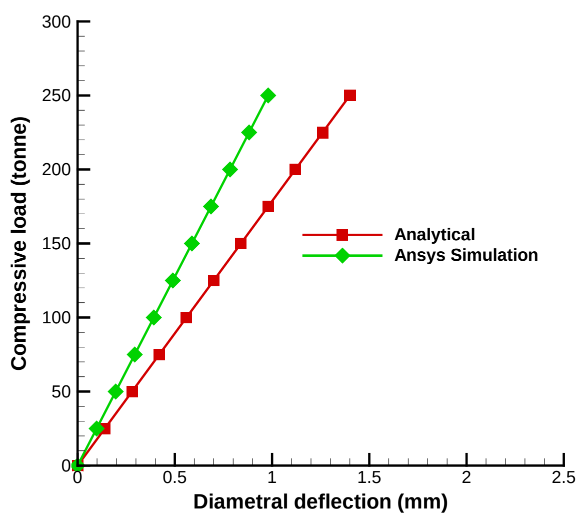



**Figure 9.** The variations of the diametral deflections of the designed proving ring for different applied loads

The diametral deflection of the designed capsule shaped proving ring depends on the applied load. This deflections for different applied loads within the elastic limit are calculated both analytically using the developed computer program and it is also investigated numerically using simulation software (Ansys). The variations of diametral deflection of the designed capsule shaped proving ring for different applied compressive load is depicted in Figure 9. A linear relation is found from the figure as it is designed and calculated within elastic limit only. It is found from the figure that the deflection found from the analytical calculation and numerical simulation are close but there are little deviations comparing the results. The reasons of the slight differences between the analytical and the numerical results are stated above already. The modification in the analytical design so that it can accommodate accessories and can be easily manufactured locally causes the little deviations between analytical and numerical results. Besides, a complete 3D model of the proving ring is used in the simulation but in analytical calculations, the cross section of the proving ring is considered. So, little deviation that is found in Figure 9 is not surprising.

Finally, the complete proving ring with necessary accessories is illustrated in Figure 10. The base is needed to mount the proving ring and the load is applied on the top attachments. A digital micrometer dial indicator gauge can measure very little diametral deflections so precisely. According to the current study, the design process of a capsule shaped proving ring with variable rectangular cross section with a load measuring capacity of 250 tonnes is complete and it is ready to proceed further for the manufacturing process in near future.

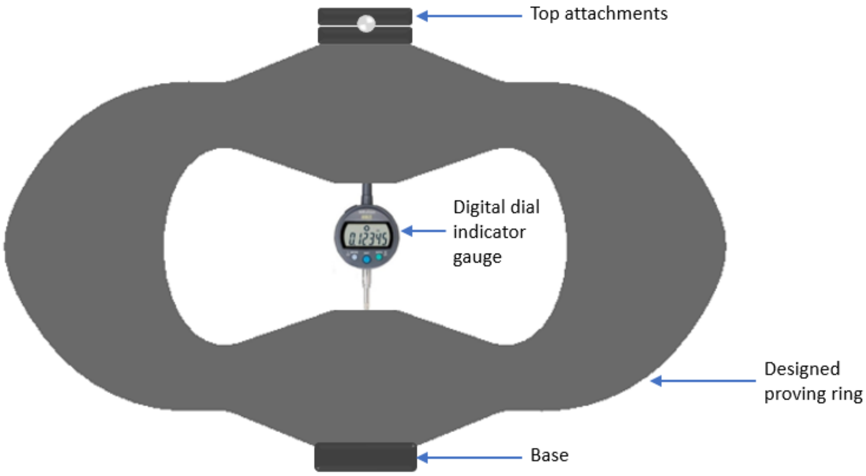



**Figure 10.** Illustration of complete proving ring structure with necessary accessories

## 5. Conclusion

The complete design of a capsule shaped proving ring with variable rectangular cross section with a load measuring capacity of 250 tonnes is conducted in this study. Locally available structural steel is chosen as the material of the proving ring. This proving ring is specially designed to calibrate the universal compression testing machine of the solid mechanics laboratory of the Department of mechanical engineering at Bangladesh University of Engineering and Technology (BUET) but it can be used in any other machines of requiring similar dimensions for different purposes. A computer program based on MATLAB is developed for analytical calculations to find the optimum dimensions of the proving ring. After finding the optimum dimensions, a 3D model of the proving ring of actual size is developed using Solidworks after necessary modifications in design. Finally, that 3D model of the proving ring is numerically simulated using Ansys. The numerical results are almost same with analytical results but there are little deviations in some parameters that occur due to different assumptions and modifications of the analytical design. These little deviations do not hamper the reliability of the proving ring and the optimum design that is found in this study is satisfactory. This capsule shaped proving ring is designed in such way so that it can be manufactured locally with locally available materials. So, designing and manufacturing this kind of industrial instruments locally in Bangladesh is really necessary to keep up with the industrial and technological advancements in this country. The authors of this study are leaving it here for the researchers and engineers for future investigations on developing efficient manufacturing processes locally to manufacture such kind of important industrial instruments.

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## References

Timoshenko, S., *Strength of Materials, Part I and II*, $2^{nd}$ Edition, D. Van Nostrand, 1941.

Reid, S. R. and Bell, W.W., Influence of strain hardening on the deformation of thin rings subjected to opposed concentrated loads, *International Journal of Solids and Structures*, vol. 18 (8), pp. 643-658, 1982.

O'Dogherty, M. J., The design of octagonal ring dynamometers, *Journal of Agricultural Engineering Research*, vol. 63 (1), pp. 9-18, 1996.

Yaniv, S. L., The Proving Ring, Available: https://www.nist.gov/publications/proving-ring-0, February 1, 2003.

Rahman M. A., Rahman, S., Noman, K. N. A., and Islam, S, "Optimum design of a proving ring". *Proceedings of 2nd BSME-ASME International Conference on Thermal Engineering*, Dhaka, Bangladesh, pp.1123-1128, January 2-4, 2004.

Rahman M. A., Rahman, S. and Noman, K. N. A., Optimum design of a circular proving ring with variable cross sections, *Transactions of Hong Kong Institution of Engineers*, vol. 11, pp. 53-55, 2004.

Rahman M. A. and Rahman, S., Design parameters of a circular proving ring of uniform strength, *Proceedings of 6th International Conference on Mechanical Engineering*, Dhaka, Bangladesh, December 28-30, 2005.

Rahman, M. A., Kowser, M. A. and Hossain, S. M. M., Large deflection of the cantilever steel beams of uniform strength - experiment and non-linear analysis, *International Journal of Theoretical & Applied Mechanics, Research India Publications*, vol. 1 (1), pp. 21-36, 2006.

Rahman, M. A. and Kowser, M. A., Nonlinear analysis of cantilever shape memory alloy beams of variable cross-section, *Smart Materials & Structures (IOP Publishing Ltd., UK)*, vol. 16, pp. 531-540, 2007.

Budynas, R. G. and Nisbett, J. K., *Shigley's Mechanical Engineering Design*, 9$^{th}$ Edition, McGraw-Hill Education (India) Private Limited, 2013.

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