Standalone Software Development for selection and analysis of Base Isolators

Abhishek Sarkar

MS Candidate, Structural Engineering

Stanford University

Curriculum Practical Training

Prof E Miranda

Professor, Civil and Environmental Engineering Department,

Stanford University

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Introduction

Earthquake Protection Systems is one of the leading manufacturers of Triple Friction Pendulum base Isolation Systems in the world. The company is responsible for isolating San Francisco International Airport, the largest base isolated structure in the world till date. The in-house facilities enable the company to perform earthquake simulations on every bearing that is shipped out to clients. This enables the company to maintain high standards of efficiency and quality.

As an intern, I am responsible for developing a standalone interactive interface that performs an informed selection of bearing parts based on parameters set by clients. The interface also comes with an option of generating AutoCAD drawings and reports in docx format as per company's requirements and templates. The program generates 9-10 pages of report in the company prescribed templates at the click of a button. The reports contain all the necessary bearing specifications, bearing displacement capacities, vertical load capacities and other miscellaneous information. The program also displays the five –stage hysteresis loop, displacement demand loops based on supplied spectra and bearing drawings at the interface. In addition, all the important specifications of the bearings are displaced in a textbox before the final report is generated, to enable the user to come to an informed decision.

The coding of this interface is done in MATLAB R2015a with the help of GUIDE. Complex algorithms are used for the purpose of report generation as Matlab was synced with MS Word.

Triple Friction Pendulum Isolator Theory

A Triple Friction Pendulum Isolator System is broadly composed of three parts namely, the Main (outer) Concave, the Slider Concave and the Inner Slider. There are two Main Concaves and two Slider Concaves and one Inner Slider. The bottom Main Concave is fixed to the base plate which in turn sits on a concrete foundation and is hence fixed. All the other parts are mobile with different displacement capacities. The following diagram shows the various parts of a TFP isolator.

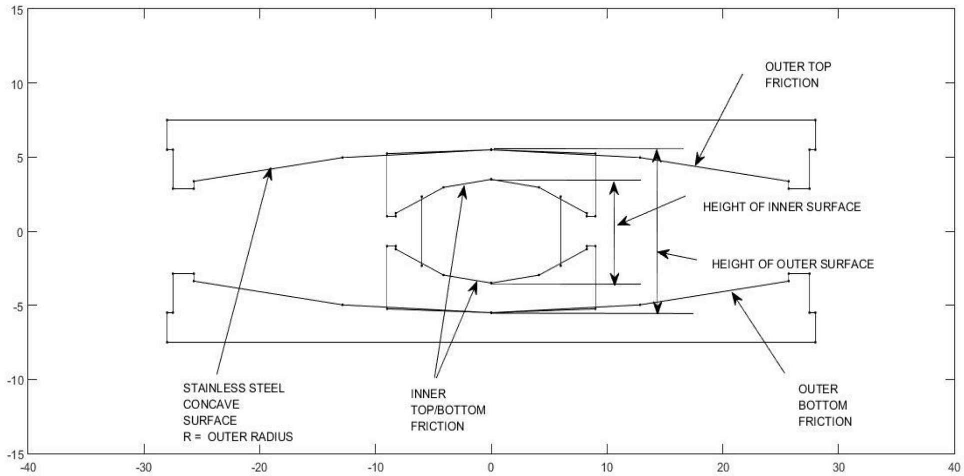


Figure 1: TFP Isolator (Schematic diagram), Source: Matlab2015a generated image

Each of these parts is machined out of casted steel blocks by EPS in their in-house workshop to various sizes based on project requirements. Each TFP isolator has four sliding surfaces, one between the Lower Main Concave and Lower Slider Concave, one between the Lower Slider Concave and the Inner Slider, one between the Inner Slider and the Upper Slider Concave and the one between the Upper Slider Concave and the Upper Main Concave from bottom to top respectively. Each of these sliding surfaces is associated with certain coefficients of friction that governs the order of sliding of these parts. These frictions have certain tolerances that are set by EPS as the upper and lower bound friction properties.

Typically, for all standard bearings, the frictions between the inner slider and the upper and lower slider concaves are made equal and are set to be the minimum, followed up by the friction between the slider concave and the lower main concave. The friction between the slider concave and the upper main concave is the highest of all. This enables the TFP to maximize its displacement capacity.

When a lateral force is applied to the bearing, the inner slider moves first on both its surfaces, followed by the movement of the lower slider concave. Friction properties are set such that the lower slider starts moving before the inner slider reaches its displacement limit. All this while the upper slider concave and the upper main concave moves as the same unit. The frictions should further be modulated such that the upper slider concave starts moving relative to the upper main concave before the lower slider concave reaches its displacement limit.

Upon unloading, the parts move in the same order as described above. The un-displaced and displaced configurations of the bearing are shown below.

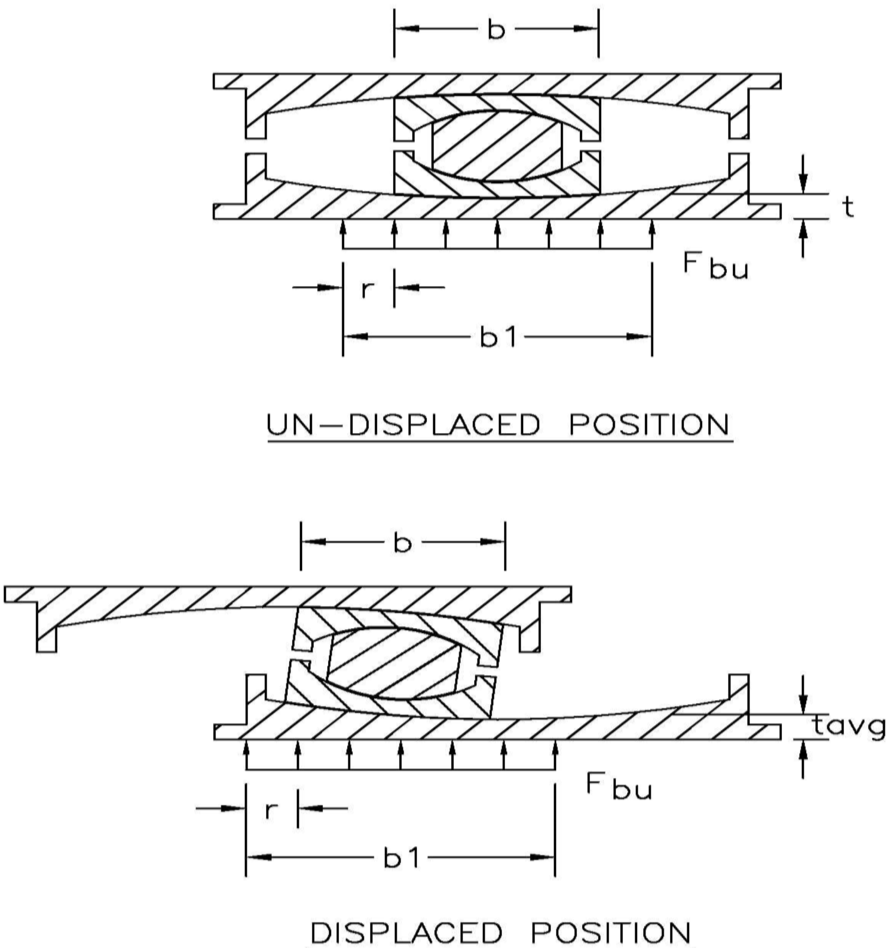


Figure 2: Displaced and un-displaced positions of a bearing

In selecting parts, care should be taken to make sure that the outer radius of the slider concave is comparable with the inner radius of the main concave to facilitate smooth sliding without imbalance.

Five-Stage Hysteresis Loop

TFP isolators exhibit five distinct phases in the force-displacement plot known as ‘regimes’. The five regimes attribute to the following:

- The first force-displacement behavior takes place only when the inner slider slides are relative to the lower slider concave.
- The next phase begins when the lower slider concave starts sliding and the inner slider remains stationary in the displaced position.
- The third regime commences when the upper slider concave starts sliding relative to the upper main concave.
- The forth regime exhibits the stiffening behavior of the hysteresis loop when the bottom slider concave hits the displacement retainer. This forces the inner slider to start sliding relative to the lower slider concave.

- The fifth regime exhibits further stiffening behavior when the top slider concave hits the displacement retainer. The sliding takes place between the inner slider and the two slider concaves.

End of fifth regime denotes the displacement capacity of the bearing. In most cases the fifth regime is kept as a reserve capacity. All the calculations are done based on the displacement obtained at the end of the fourth regime.

The figure below shows a typical force displacement loop

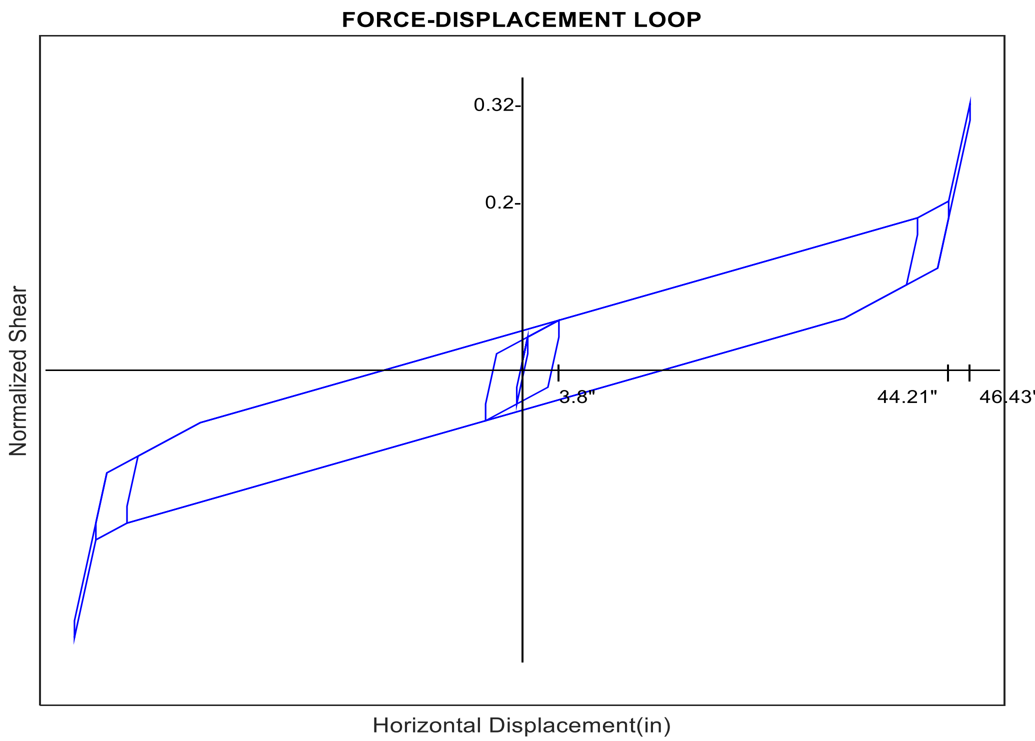


Figure 3: Hysteresis Loop, Source: Matlab Generated image

Structure & Generation of GUI

GUIDE was used for initial generation of GUI structure and positioning of various icons on the GUI. Every action button on a GUI has a ‘tag’ by which it is referenced in a program. The referencing is used to perform the tasks which the button is proposed to perform upon clicking by the user. A function named ‘Handle’ is used to call the tags of various action buttons upon clicking, which reroutes the controls to specific callback functions generated by GUIDE. These callback functions contain the codes to perform desired tasks.

Depending upon the complexity of the code, it is sometimes needed to use the information available in a *Callback* function by other *Callback* functions to perform certain tasks. However, these functions cannot be used to send information via Call-by-Value as is the case for other regular functions, since the callbacks are directly linked to the GUI and can only receive information from the GUI. Hence, to send data across, the approach of storing variables in root directory is used. Root directory is that folder where Matlab software is installed. *Matlabroot()* is the command used to access information on the location of root directory. Once the variables are stored in the root directory, it can be accessed by all the other callback functions as and when necessary.

The left hand side of the GUI is used to input the parameters needed to conduct the analysis and the right side of the GUI is used to display plots and bearing properties.

The top left side of the GUI contains the 'select parts' panel. It contains two pop down menus that lists the standard EPS manufactured parts of main concaves and slider concaves respectively. Upon selecting the slider concaves, the inner sliders get automatically selected as matching pairs. At this stage the program calculates the rotational capacity of the bearing based on bearing height. The Compatibility check push button pops up a menu that says whether the rotational capacity for the selected bearing is adequate or not. The database pushbutton displays the complete set of bearing parts available in EPS warehouse along with the quantities of each part in stock.

Below this panel, there is a set of three push buttons that are used to create custom parts for special bearings. These parts are used when dealing with unusual requirements of clients. EPS manufactures these bearings upon special orders. As soon as they are created, they get automatically added to the database along with their quantities.

Following the selection of bearing types, comes the selection of friction properties. Since, most standard bearings have same coefficients of friction between the upper/lower slider concaves and the inner slider, three edit boxes are available to input the friction values. To incorporate manufacturing tolerances, slots are provided to input the upper and the lower bound friction properties as well. Hence, in total, nine text boxes are created to input the friction properties of the bearing. This is the most important part as the entire hysteresis loop characteristics are dependent on these properties.

The next panel inputs the MCE and the DBE level design spectra properties. Edit boxes are created to input the Sm1 and Sd1 values respectively. The DBE spectra is used for upper bound friction properties and the MCE spectra is used for the Lower Bound friction properties. The EPS proposed nominal values can be used for both DBE and MCE depending upon the project requirement. A checkbox is created to facilitate this option.

Finally, a panel is there for report generation in either SI or Imperial units. On clicking the push button, all the reports are generated in different word files (docx format). The templates of these files are so designed to match the company requirements precisely.

To the right of the select-bearing-parts panel, there exists a panel that contains a pushbutton to generate all necessary bearing summary, schematic bearing drawing (to scale), 5 stage hysteresis behavior and the displacement demand plot. This essentially forms the output section of the GUI.

The following figure shows the home page of the GUI:

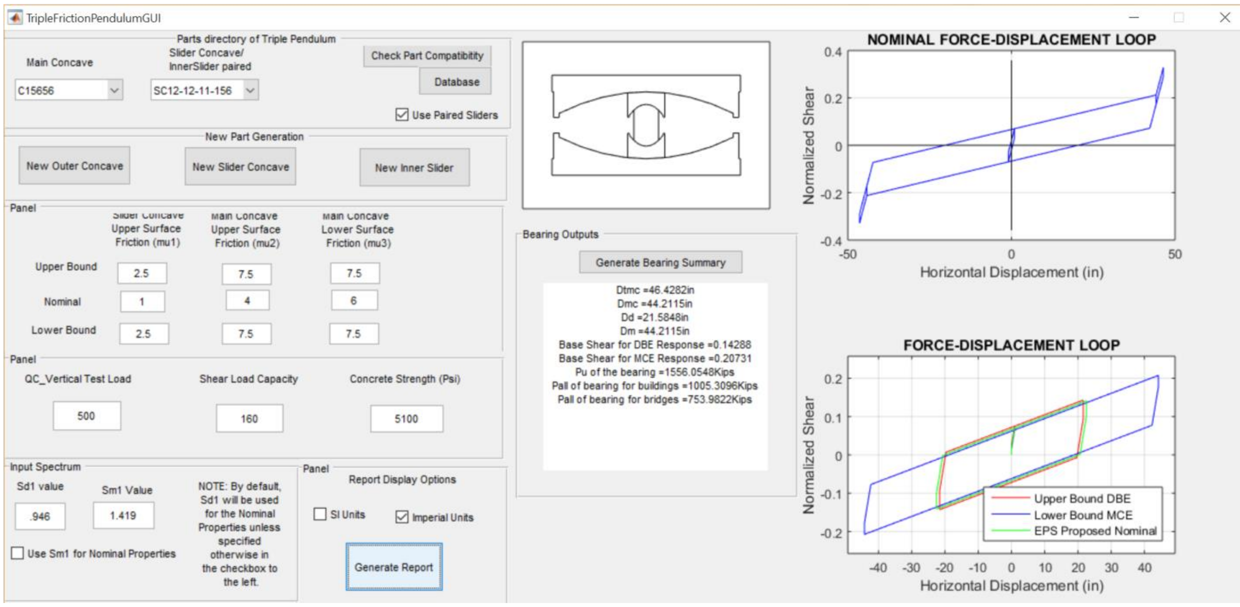


Figure 4: GUI Interface

Displacement Demand Calculations:

The displacement demand calculations are an iterative process that depends on a convergence point. The calculations starts with an arbitrary displacement demand, preferably the displacement value at the end of the fourth regime. Any displacement value obtained from the spectrum if found to be greater than the stage four value, the bearing is declared to be inadequate for the given spectrum.

The following steps are observed for the calculation of displacement demand:

1. The displacement demand is set to regime 4 displacement as default.
2. Hysteresis loop is generated based on displacement demand, geometric and nominal/upper bound/lower bound friction properties of the bearing.
3. Keff is calculated as a function of maximum normalized forced over maximum displacement.
4. Teff is calculated from Keff.
5. Area enclosed by the hysteresis loop is calculated.
6. From the enclosed area damping coefficient is calculated.
7. From ASCE 7-10, AASHTO equation, the damping reduction factor is calculated.
8. Displacement demand is calculated from the design spectra (DBE/MCE).
9. If the displacement demand calculated from the spectrum is found to be less than the displacement demand set in step1 and within 5% tolerance, the loop is exited. Otherwise,

steps 2 through 9 are repeated with the value of displacement demand calculated in step 8.

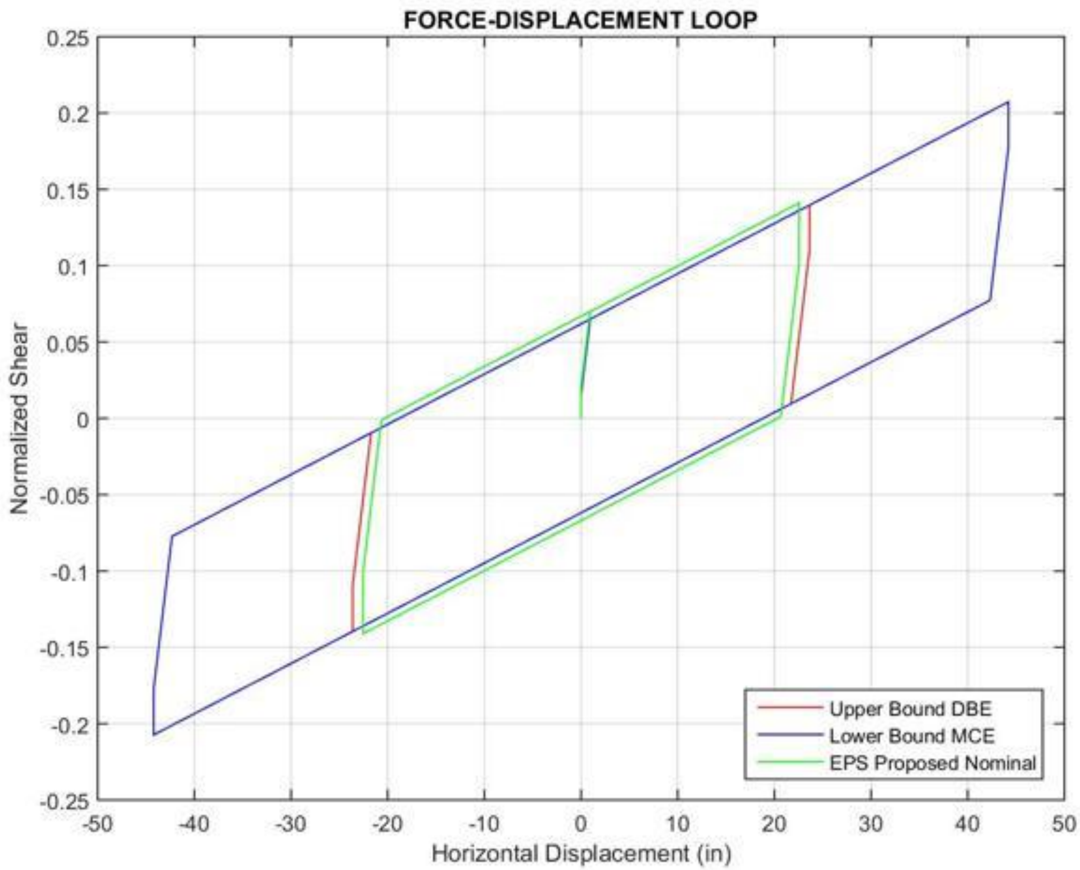


Figure 5: Displacement Demand plots, Source: Matlab generated image

The above calculations are carried out for DBE spectrum (Lower Bound Frictions), MCE spectrum (Upper Bound Frictions) and again DBE spectrum (Nominal Frictions).

Vertical Load Capacity

The vertical load calculations are performed on the displaced and un-displaced positions of the isolator. The loads are transmitted to the base foundation at an angle of 45 degrees and is distributed over a circular bearing area.

Report Generation Technique

Matlab is empowered with extensive report generation algorithms. PDF and DOCX reports can be generated after syncing Matlab with MS word. 'mlreportgen.dom.*' contains all the built-in library classes required for report generation in Matlab. It needs to be imported into the code before generating a docx file.

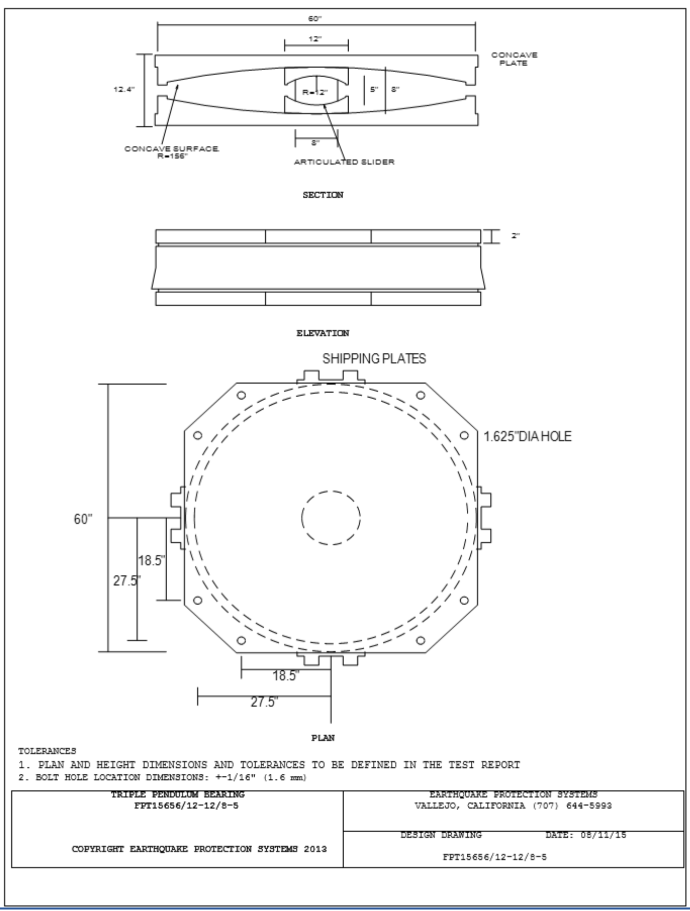
MS Word has the feature of incorporating rich text inline holes in customized word templates, which are used to create reports. It gives the much needed flexibility in formatting the documents. The rich text holes are referenced by Matlab codes to input texts, images and figures as and when necessary. This is the most advanced technique used for auto generating reports, and is essentially a new feature of Matlab 2015a.

The text below shows a sample report generation code. The report generated by this code contains the section, elevation and the plan views of the bearing drawings.

```
import mlreportgen.dom.*
doc=Document('TRIPLE PENDULUM BEARING_1','docx','mytemplate_1');
while ~strcmp(doc.CurrentHoleId, '#end#')
    switch doc.CurrentHoleId
        case 'OC'
            str1=mat2str(temp1(1),3);
            str2=mat2str(temp1(2),2);
            append(doc,strcat('FPT',str1,str2));
        case 'SC1'
            str1=mat2str(temp2(1));
            append(doc,str1);
        case 'SC2'
            str1=mat2str(temp2(2));
            append(doc,str1);
        case 'IS1'
            str1=mat2str(temp3(1));
            append(doc,str1);
        case 'IS2'
            str1=mat2str(temp3(2));
            append(doc,str1);
        case 'section'
            append(doc,I1);
        case 'elevation'
            append(doc,I2);
        case 'plan'
            append(doc,I3);
```

```
case 'plan'
            append(doc,I3);
        case 'date'
            formatOut = 2;
            str = datestr(now,formatOut);
            append(doc,str);
        case '15'
            append(doc, '+-1/16" (1.6 mm)');
    end
    moveToNextHole(doc);
end
close(doc);
```

The page generated by this particular code is shown below.



References

[1] Frenz Daniel M, Constantinou M C, Spherical Sliding Isolation Bearings with Adaptive Behavior:Theory, Wiley Interscience, 37, 2007, 163-183.

[2] “Matlab Report Generator Users guide”, www.mathworks.com, March, 2015