NEO Test Stand Analysis

SwampWorks Mechanical Design and Testing Intern Report

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A project within SwampWorks is building a test stand to hold regolith to study how dust is ejected when exposed to the hot exhaust plume of a rocket engine. The test stand needs to be analyzed, finalized, and fabrication drawings generated to move forward. Modifications of the test stand assembly were made with Creo 2 modeling software. Structural analysis calculations were developed by hand to confirm if the structure will hold the expected loads while optimizing support positions. These calculations when iterated through MatLab demonstrated the optimized position of the vertical support to be 98'' from the far end of the stand. All remaining deflections were shown to be under the 0.6'' requirement and internal stresses to meet NASA Ground Support Equipment (GSE) Safety Standards. Though at the time of writing, fabrication drawings have yet to be generated, but are expected shortly after.

Nomenclature

80/20	=	A manufacturer of a popular modular, easy to use, profiled aluminum material
CAD	=	Computer Aided Design
COTS	=	Consumer Over-The-Shelf Parts
KSC	=	Kennedy Space Center
ISRU	=	In-Situ Resource Utilization
GMRO	=	Granular Mechanics Resource Operations
GSE	=	Ground Support Equipment
NASA	=	National Aeronautic and Space Administration
NEO	=	Not an acronym, used as the Greek prefix for "new"
SLF	=	Shuttle Landing Facility
TRL	=	Technology Readiness Level
W-beam	=	Wide flanged I-beam

I. Introduction

SwampWorks is a research lab in Kennedy Space Center (KSC) focused on attempting new ideas for In-Situ Resource Utilization (ISRU) and exploring extra-terrestrial bodies. Leveraging modern technology to create innovative solutions that interact with challenging environments and overcome factors such as erosion, dust mitigation, and micro gravity to name a few. This lab uses rapid prototyping of these ideas while they are still in a low Technology Readiness Level (TRL) and have established partnerships with dozens of companies and universities to enable this type of lean development. In a lab like this there are many projects being started and handled on a daily basis by multiple engineers, scientists, and interns.

One project focuses on studying and observing the regolith ejection plume effects from rocket exhaust as landing vehicles descend to a planetary or lunar surface. The goal of the intern project is to analyze and finalize the test stand design to begin construction for an experiment at a point after the internship is over. The analysis will be done to an existing initial design to determine if the stand will hold up to the loadings and worst case scenario forces acting on the structure. Then if any improvements can be made, the changes will be added to the Computer Aided Design (CAD) model so that fabrication drawings can be generated. Once drawings are obtained, the next phase is to begin

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construction of test stand sections that can be prepared in advance. Eventually when the experiment is ran in the future. The data will most likely be used for mission planning or to generate methods to mitigate erosion of equipment on lunar or planetary surfaces due to regolith kicked up from a landing vessel.

II. Objective

Like mentioned before, the aim of this intern project is to produce finalized fabrication drawings and begin construction of the test stand for a later experiment. Which incorporates analysis and design milestones along the way to reach. The overall milestones of the project that includes this are listed below:

1. Add design changes specified by mentoring engineer to the CAD model of the structure
2. Complete beam loading analysis on the structure to determine where the optimal position of the vertical support shall be
3. Confirm if stresses stay under a 2:1 ratio for yield and 3:1 for ultimate stress of A36 steel as per NASA GSE Safety Factor outlined in NASA-STD-(I)-5005C section 5.1.2.1 [1]
4. Confirm deflections of the structure stay under 0.6’’ with the regolith trough in any position
5. If needed, add any small finishing touches to the CAD model to generate drawings
6. Generate and print fabrication drawings
7. Assemble the regolith trough and aid fabrication of the support structure if time allows

III. Technical Approach

A. Modeling Approach:

To incorporate the design changes to the CAD assembly. Creo 2.0 modeling software was used to manipulate each part model and the overall assembly that incorporates hundreds of these parts. The initial design assembly needed changes applied to it that were requested by the mentoring engineer on the project and issues with how the Consumer Over The Shelf (COTS) parts were imported into the assembly required a complete rebuild. This, combined with adding the optimized leg support changes, required a substantial amount of work to be done to the model. The approach taken, was to only include sub-assemblies for only pre-fabricated components that would be brought in as one whole piece. Then bring in the remaining components individually and make use of patterning when possible to reduce the time to completion.

B. Analysis Approach:

At this point it’s best to explain the overall geometry of the test stand. As there are two portions of the test stand shown in the image above. The top portion is the regolith trough built in aluminum 80/20 (in grey) hardware that will hold a large quantity of regolith simulant material. The support structure below that (in brown) is built using W6x20 wide flanged W-beams for the horizontal and vertical supports that connect to the side of the SLF Runway on the left and then to square concrete footers that rest on the surrounding ground soil. This support structure is the focus of the analysis as this has been done for the trough already and the support structure will be seeing the greatest stresses of the two.

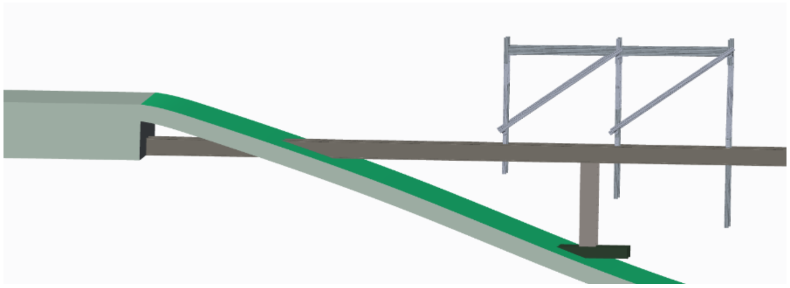


Figure 1: Neo Test Stand basic geometry

For the beam analysis, two factors are key to observe and drive the final design, and along with it, where the vertical support shall be positioned to minimize these. Bending stress and deflection of the horizontal W-beam. As too much bending stress could potentially cause the beam to permanently deform or break and too much deflection will hinder the experiment results. Also, as a requirement, the regolith trough needs to be placed anywhere along the structure;

increasing the complexity of variables that change. Thus a very rigid support structure is required and analysis is focused on the horizontal W-beam since the greatest deflections will be seen in this beam due to the nature of its loading. These can be evaluated by using mechanics of materials methods to produce the equations of equilibrium for the external reaction forces of the structure. Then in this case, the method of superposition was implemented to find the deflection at two locations (shown in the figure below as δ_1 *and* δ_2) on the beam due to each type of force being applied to the horizontal W-beam and summed together to produce the final deflections. The simplified free body diagrams demonstrating both of these are shown below.

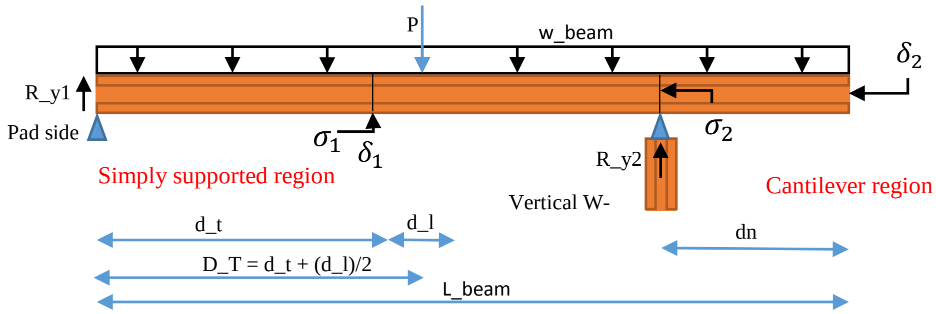


Figure 2: Free Body Diagram of Horizontal Support Beam

Table 1: Diagram key

P	=	Simplified weight of the trough (two point loads reduced to one)
w_beam	=	Distributed weight of the horizontal beam
R_y1	=	Reaction force from the pad
R_y2	=	Reaction force from vertical support
δ_1	=	Point of interest for vertical deflection in the SS region
δ_2	=	Point of interest for vertical deflection in the Cantilever region
σ_1	=	Point of interest for internal bending stress in the SS region
σ_2	=	Point of interest for internal bending stress in the Cantilever region

The equations and mathematics needed to solve this will be explained further in the Results and can be viewed in the appendix. As the loading of the trough needs to be able to be placed anywhere along the horizontal beam. A situation where the vertical support positioned is being varied while the trough position is also being varied created two sets of equations to describe what happens to it. The deflections and stresses on the structure based on if the trough is before or after the vertical W-beam support; denoted as the Simply Supported Region or Cantilever Region in the diagram above. Thus MatLab was employed to iterate the vertical beam support inward towards the pad (shown as dn on in the diagram above). Then in each iteration of the support, the loading from the regolith trough is ran down the entire beam, recording the deflections and stresses at the interest points as it went along. If a good set of deflections were observed; for example, a set where all deflections are under 0.6'' for both sides of the horizontal beam. The Vertical beam position is saved for comparing to other valid sets to determine the best position to reduce deflection.

To also note, the reason why deflection is focused on more heavily than internal stresses is due to the nature of the geometry of the beam loading and the material used. As with many construction metals in general, the material can yield or deflect to a degree while having relatively low internal stresses or stresses that are still considered safe [2]. Which can be amplified depending how long the beam is and how it is loaded. This is shown to happen here too in the results as the horizontal beam that is about 32 feet in length potentially could deflect 1.5 inches if the support is located as far away as possible, but the stresses seen are still below the 2:1 yield and 3:1 ultimate strengths of A36 steel as per the NASA GSE Safety Factor [1]. This is a good case why structural beams will often be designed to be stronger than needed to reduce deflections as much as possible [2].

IV. Results

Beam Analysis Results:

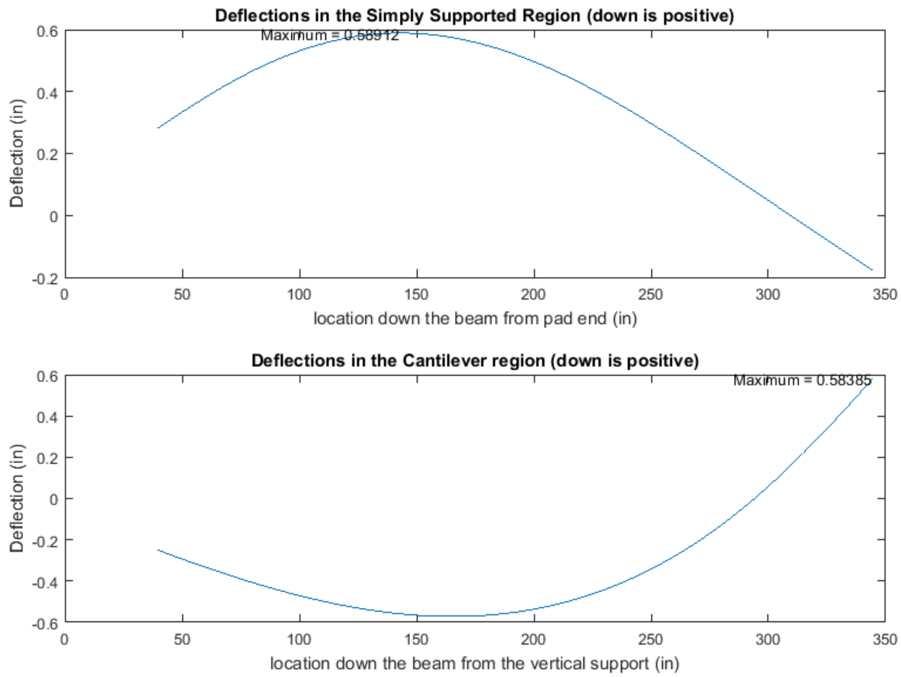


Figure 3: Matlab Deflection Plot for both regions of Horizontal Support @ 98'' from far end

The figure above illustrate the deflection of the two points of interest as the loading from the Regolith Trough is moved down the beam from the pad side to the very end. Showing very well how the center of the simply supported region reacts and the end of the cantilever region reacts as the load further increases to the maximum point along the structure. With the max deflections occurring in the expected areas of each simplified region, being in the center of the simply supported region and at the end of the cantilever region. Since there are two variables that were iterated, the position of the vertical support and position of the trough, this figure is of the best case that features the lowest maximum deflection for the given position of the vertical support. Which was found to be at 98 inches from the far side of the horizontal support (which is dn in figure 2).

For the stresses, Matlab was set to calculate the stresses only when a best case scenario was found and are shown below:

Table 2: Resulting Internal Bending Stresses

Point of interest	Resulting Internal Bending Stress (lb/in^2)
σ_1	0.5891 psi
σ_2	5,720 psi or 5.72 ksi

Referencing an online database, the material properties that we are considering of this steel to are:

Table 3: A36 Steel Properties [3]

Property and Symbol	Value
Tensile Yield Strength, σ_y	36300 psi or 36.3 ksi
Compressive Yield Strength, σ_y	22000 psi or 22 ksi
Ultimate Tensile Strength, σ_u	58 - 79.8 ksi

Observing the bending stress results in table 2 to the yield and ultimate strengths of the steel material. It's easy to see that the highest stress seen of 5.72 ksi is below either yield strength and also well below the ultimate strength. Resulting in ratios of 3.84:1 for yield and 10.14:1 for ultimate. Satisfying the NASA GSE safety standard.

Modeling Results:

Modeling resulted in a grueling effort to tear down and remake the entire assembly. As 90% of the model contains COTS parts that were incorrectly imported and required re-import and assembly. In the figures to the standht illustrate the requested added design changes. With a list below with the following changes:

Table 4: Change List

Action	Status
Re-import all COTS items	completed
Dissolve sub-assemblies to individual components except the Regolith Trough	completed
Replace anchor bolts to $5/8^{th}$ stud anchors	Completed
Add angle brackets to W-beam to W-beam connections	Completed
Add wall retainer brackets for regolith trough	Completed
Delete redundant vertical support and position optimized support	Completed
Re-model Cross-Bracing parts	Completed
Add new concrete footers and supporting connection plates and brackets	In - Progress

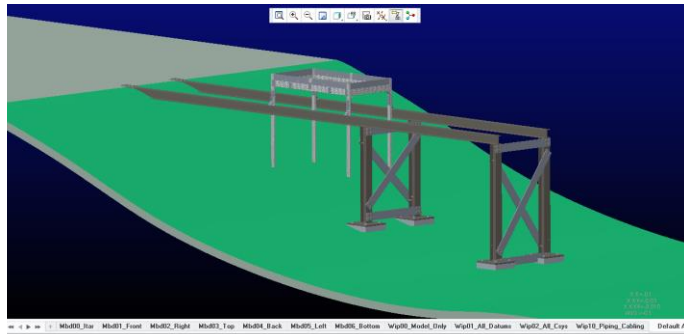


Figure 4: Old Creo Assembly of test stand

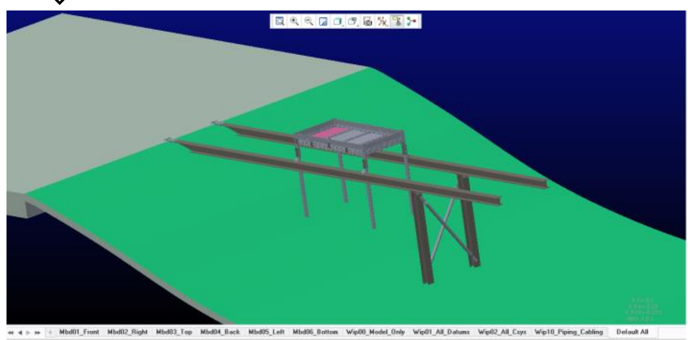


Figure 5: New Creo Assembly of test stand

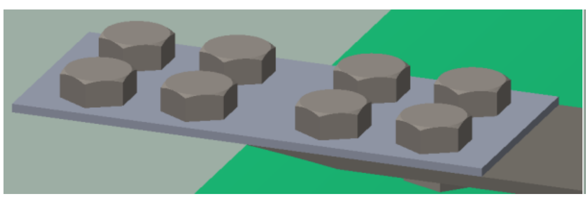


Figure 6: Old Pad Fasteners

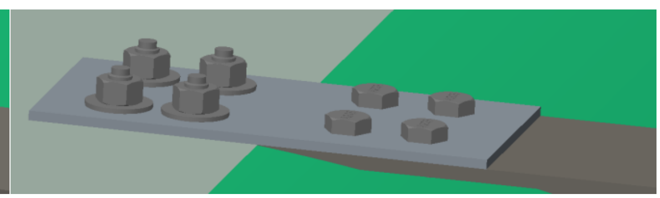


Figure 7: New Pad Fasteners

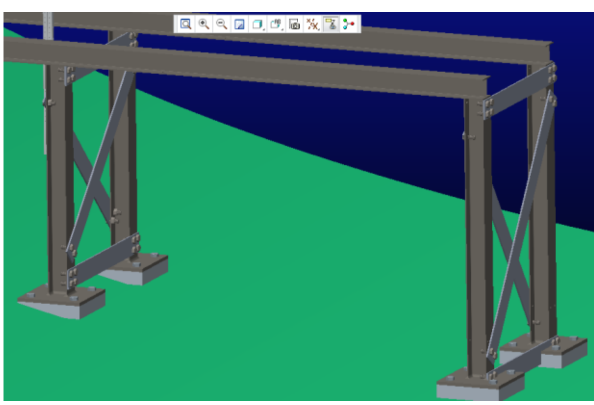


Figure 8: Old vertical supports

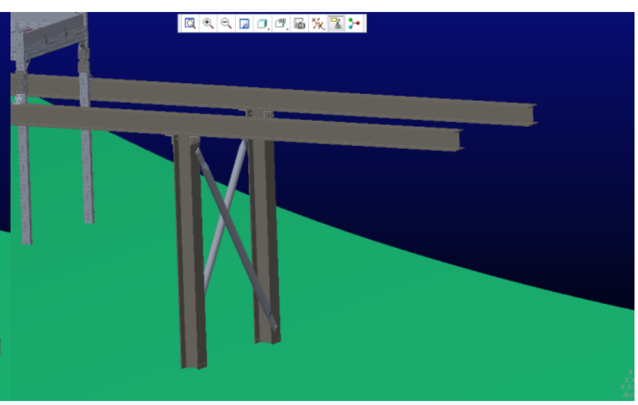


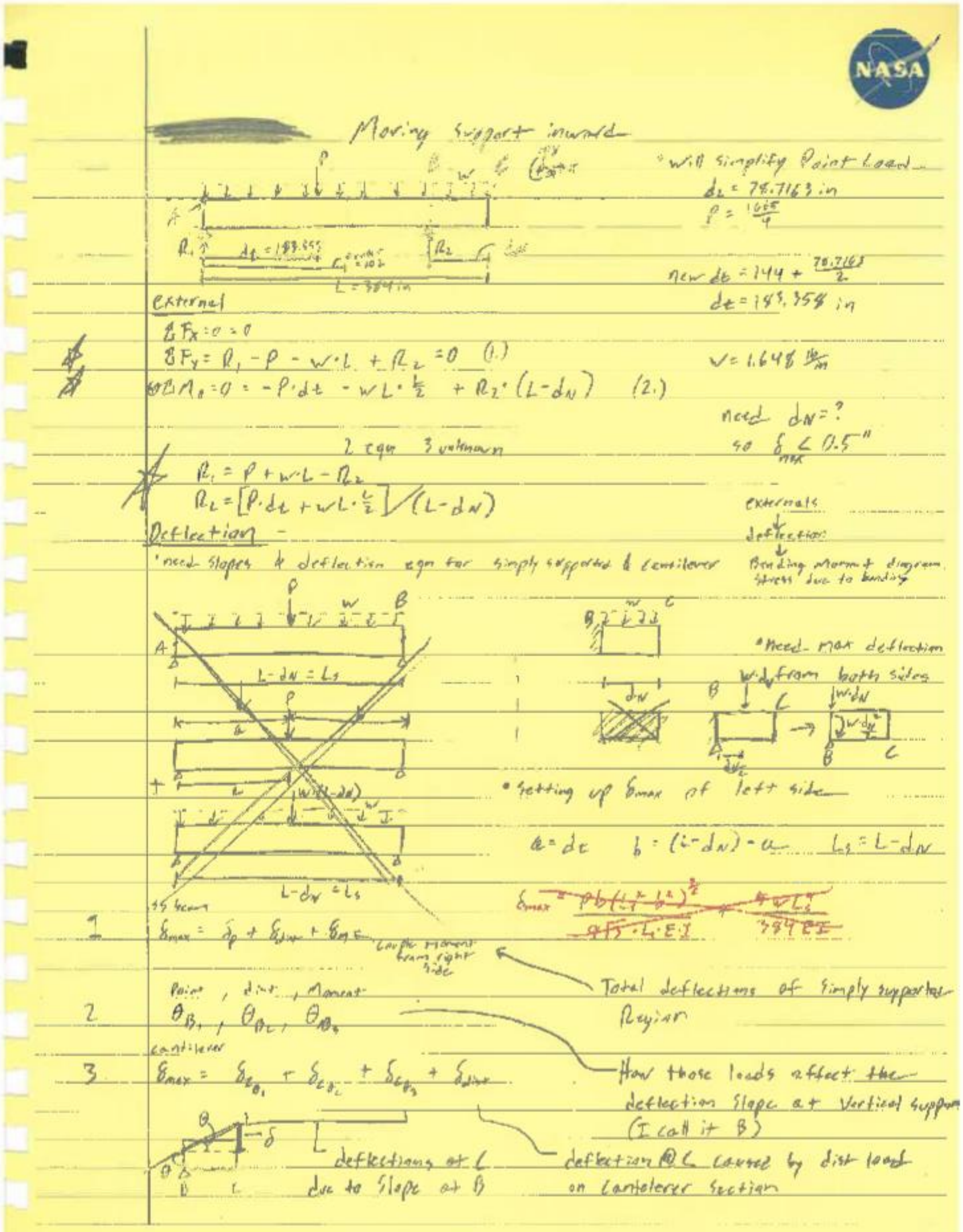
Figure 9: Single Optimized support *(no footers)*

From the before and after screenshots it is apparent that at the point of writing that this is still ongoing to replace the remaining components, but illustrate the large changes made to the model to make it realistic for fabrication.

V. Conclusion

Analysis of the structure to determine if it met requirements ended up producing two complex sets of equations to represent the reactions and deflections depending where the trough was located on the structure. This with evaluating moving the support inwards towards the pad created a multi variable situation that was solved utilizing MatLab. The analysis results of the vertical positioning show that the deflections and bending stresses are within expectations and meet safety standards for fabrication. This was reflected as a change to the CAD model as one of the major changes added. Though at the time of writing, modeling is still ongoing and the remaining objectives are expected to be completed shortly after this is completed.

Appendix



Moving support inward

*will simplify Point Load

$d_t = 78.7163$ in

$P = \frac{1665}{4}$

$d_t = 183.355$

$L = 384$ in

new $d_t = 144 + \frac{78.7163}{2}$

$d_t = 183.358$ in

external

$\Sigma F_x = 0 = 0$

$\Sigma F_y = R_1 - P - w \cdot L + R_2 = 0$ (1.)

$\Sigma M_A = 0 = -P \cdot d_t - wL \cdot \frac{L}{2} + R_2 \cdot (L - d_N)$ (2.)

$w = 1.648$ lb/in

need $d_N = ?$

so $\delta_{max} < 0.5''$

2 eqn 3 unknown

$R_1 = P + w \cdot L - R_2$

$R_2 = [P \cdot d_t + wL \cdot \frac{L}{2}] / (L - d_N)$

externals

deflection

Bending moment diagram
stress due to bending

Deflection -

*need slopes & deflection eqn for simply supported & cantilever

$L - d_N = L_s$

*Need max deflection from both sides

$w \cdot d_N$

$\frac{w \cdot d_N^2}{2}$

• setting up δ_{max} of left side

$a = d_t$ $b = (L - d_N) - a$ $L_s = L - d_N$

$\delta_{max} = \cancel{\frac{Pb(L_s^2 - b^2)^{3/2}}{9\sqrt{3} \cdot L_s \cdot EI}} + \cancel{\frac{5wL_s^4}{384EI}}$

SS beam

1 $\delta_{max} = \delta_P + \delta_{dist} + \delta_{M}$

couple moment from right side

Total deflections of simply supported Region

Point, dist, Moment

2 $\theta_{B_1}, \theta_{B_2}, \theta_{B_3}$

How those loads affect the deflection slope at vertical support (I call it B)

cantilever

3 $\delta_{max} = \delta_{c_{\theta_1}} + \delta_{c_{\theta_2}} + \delta_{c_{\theta_3}} + \delta_{dist}$

deflections at C due to slope at B

deflection @ C caused by dist load on cantilever section

Left side deflection

$a = d_t \quad b = L - d_w - a \quad L_s = L - d_w$

$$\delta_{max} = \frac{Pb(L_s^2 - b^2)^{\frac{3}{2}}}{9\sqrt{3} \cdot L_s \cdot EI} \Rightarrow P \cdot (L - d_w - a)[(L - d_w)^2 -$$

$$\delta_{max} = \frac{5w \cdot L_s^4}{384\,EI} \cdot \frac{5w \cdot (L - d_w)^4}{384\,EI} \quad (2)$$

$$\delta_{max} = \frac{ML_s^2}{9\sqrt{3}\,EI} \rightarrow \frac{-\frac{wd_w^2}{2} \cdot (L - d_w)^2}{9 \cdot \sqrt{3} \cdot EI} \quad (3)$$

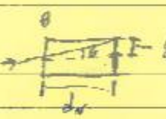
$$\delta_1 = \frac{P \cdot (L - d_w - a)\left[(L - d_w)^2 - (L - d_w - a)^2\right]^{\frac{3}{2}}}{9 \cdot \sqrt{3} \cdot (L - d_w) \cdot E \cdot I} \quad (1)$$

1A
$$\boxed{\delta_{total} = \frac{P \cdot (L - d_w - a)\left[(L - d_w)^2 - (L - d_w - a)^2\right]^{\frac{3}{2}}}{9 \cdot \sqrt{3} \cdot (L - d_w) \cdot EI} + \frac{5w(L - d_w)^4}{384 \cdot EI} - \frac{\frac{wd_w^2}{2} \cdot (L - d_w)^2}{9 \cdot \sqrt{3} \cdot EI}}$$

Slope at B

✓ · $\theta_{B_{P_1}} = \frac{Pab(2L_s - b)}{6L_s EI} \rightarrow \frac{P \cdot d_t(L - d_w - d_t)(2 \cdot (L - d_w) - (L - d_w - d_t))}{6(L - d_w) \cdot EI}$

✓ · $\delta_{c_{P_1}}$:



$\rightarrow \tan(\theta_{B_{P_1}}) = \frac{\delta_{c_{P_1}}}{d_w} \xrightarrow{\text{Using small angle}} \theta_{B_{P_1}} \cdot d_w = \delta_{c_{P_1}} \uparrow (1)$

not small: $d_w \cdot \tan(\theta_{B_P}) = \delta_{c_P}$

✓ · $\theta_{B_D} = \frac{wL_s^3}{24EI} \rightarrow \frac{w \cdot (L - d_w)^3}{24EI}$

✓ · $\delta_{c_D} \rightarrow \tan(\theta_{B_D}) = \frac{\delta_{c_D}}{d_w} \xrightarrow{\text{small angle}} \delta_{c_D} = \theta_{B_D} \cdot d_w \uparrow (2)$

not: or $\delta_{c_D} = d_w \cdot \tan(\theta_{B_D})$

· $\theta_{B_M} = \frac{-\frac{wd_w^2}{2} \cdot L_s}{3EI} \rightarrow \frac{\frac{wd_w^2}{2} \cdot (L - d_w)}{3EI}$

· $\delta_{c_M} = \tan(\theta_{B_M}) = \frac{\delta_{c_M}}{d_w} \xrightarrow{\text{small angle}}$ or $\delta_{c_M} = \theta_{B_M} \cdot d_w \downarrow (3)$

not small: $\delta_{c_M} = d_w \tan(\theta_{B_M})$

· $\delta_{max_c} = \cancel{\frac{wL_s^4}{8EI}} \rightarrow \cancel{\frac{w[L - d_w]^4}{8EI}} \downarrow (4) = \frac{w \cdot d_w^4}{8EI} \cdot (4)$

$$\delta_{total_c} = \delta_{c_P} + \delta_{c_D} + \delta_{c_M} + \delta_{D_{W}}$$

$$= -\theta_{B_P} \cdot d_N - \theta_{B_D} \cdot d_N + \theta_{B_M} \cdot d_N + \frac{w d_N^4}{8EI}$$

2

$$\boxed{\delta_{total_c} = -\frac{P \cdot d_t [L - d_N - d_t][2 \cdot (L - d_N) - (L - d_N - d_t)]}{6 \cdot (L - d_N) EI} \cdot d_N - \frac{w (L - d_N)^3}{24EI} \cdot d_N + \frac{\frac{w d_N^2}{2} (L - d_N)}{3EI} \cdot d_N + \frac{w d_N^4}{8EI}}$$

•find d_N first!

Stress due to Bending $\qquad \sigma = \frac{Mc}{I} \qquad L_s = L - d_N$

$L = 384$

$c = ?$ in

$L_s = L - d_N$

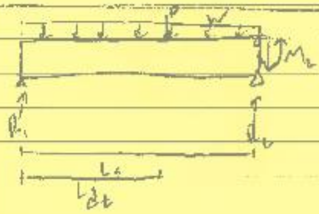
$d_t = 143.354$

Test at $d_N = 114.2$ in $\rightarrow L_s = 269.8 \qquad \frac{L_s}{2} = 134.9$

$d_N = 161.2$ in $\rightarrow L_s = 222.6 \qquad \frac{L_s}{2} = 111.4$

$$M_1 = -R_1 \frac{L_s}{2} + w \cdot \frac{L_s}{2} \cdot \frac{L_s}{4} \rightarrow M_1 = -R_1 \cdot \frac{L_s}{2} + w \cdot \frac{L_s^2}{8}$$

$$\sigma_1 = \frac{\left(-R_1 \cdot \frac{L_s}{2} + w \cdot \frac{L_s}{2} \cdot \frac{L_s}{4}\right) c}{I}$$



$$M = -R_1 L_s + P(L_s - d_t) + w \cdot L_s \cdot \frac{L_s}{2}$$

$$M = -R_1 L_s + P(L_s - d_t) + \frac{w L_s^2}{2}$$

$$\sigma_2 = \frac{\left[-R_1 L_s + P(L_s - d_t) + \frac{w L_s^2}{2}\right] c}{I}$$

Code Plan

Case 2 Simply Supported

→ Steps 1" $\frac{L-d_t}{\text{steps}}$
Block → N points =
→ ~~[illegible]~~
→ d_t vector of points = zeros(N points)
↳ d_t starts w/ $\frac{d_t}{2}$
~~[illegible]~~
→ Iterate d_w
↳ Iterate d_t 1 to Block
↳ check which side
↳ solve for δ_1 & δ_2
↳ Check if δ_1 & δ_2 vectors are all under 0.5"
Store max deflection for each d_w → if yes → store d_w → clear δ_1 & δ_2
no → dont store d_w → clear δ_1 & δ_2

$\boxed{\text{In end, find min } \delta \text{ \& display associated } d_w}$

Math

992 Steel
Not A-36

d_w & d_t = variables

$L_s = L - d_w$

external

$\Sigma F_x = 0$

$\Sigma F_y = 0 = -P - w \cdot L + R_1 + R_2 \quad (1.)$

$\Sigma M_A = 0 = -w\frac{L^2}{2} - P d_t + R_2 L_s \quad (2)$

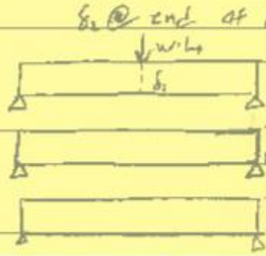
$\rightarrow R_2 = \dfrac{w\frac{L^2}{2} + P d_t}{L_s} \quad (1)$

$R_1 = w \cdot L + P - R_2 \quad (2)$

Deflection

- Want to find δ_1 @ center of SS section
  δ_2 @ end of Cantilever

LHS



$M_P = P \cdot (d_t - L_s)$

$M_w = w \cdot d_w \cdot \frac{d_w}{2} = w\frac{d_w^2}{2}$

$\delta_1 = \delta_w - \delta_{Mp} - \delta_{Mw}$

$M_p = P \cdot (d_t - L_s)$

$M_w = w \cdot \frac{d_N^2}{2}$

$\delta_w = \frac{5 w L_s^4}{384 EI}$ $\quad \delta_{Mp} = \frac{M_p \cdot L_s^2}{9\sqrt{3} EI}$ $\quad \delta_{Mw} = \frac{M_w \cdot L_s^2}{9\sqrt{3} EI}$

$$\boxed{\delta_1 = \downarrow - \swarrow - \swarrow}$$

RHS

$\delta_2 = \delta_p + \delta_w - \delta_{\theta w} + \delta_{\theta mp} + \delta_{\theta mw}$

$\theta_w = \frac{w L_s^3}{24 EI} \rightarrow \tan\theta_w = \frac{\delta_{\theta w}}{d_N} \rightarrow \delta_{\theta w} = d_N \tan\theta_w$

$\theta_{mp} = \frac{M_p L_s}{3 EI} \rightarrow \tan\theta_{mp} = \frac{\delta_{\theta mp}}{d_N} \rightarrow \delta_{\theta mp} = d_N \cdot \tan\theta_{mp}$

$\theta_{mw} = \frac{M_w L_s}{3 EI} \rightarrow \delta_{\theta mw} = d_N \cdot \tan(\theta_{mw})$

$\delta_w = \frac{w \cdot d_N^4}{8 EI}$; $\delta_p \Rightarrow a = d_t - L_s$, $b = d_N - (d_t - L_s)$

$\rightarrow \delta_p = \frac{P \cdot a^2}{6 EI}(3 \cdot d_N - a)$

$$\boxed{\delta_2 = \frac{P \cdot a^2}{6 EI}(3 d_N - a) + \frac{w \cdot d_N^4}{8 EI} + d_N \cdot \tan\theta_{mp} + d_N \cdot \tan\theta_{mw} - d_N \cdot \tan\theta_w}$$

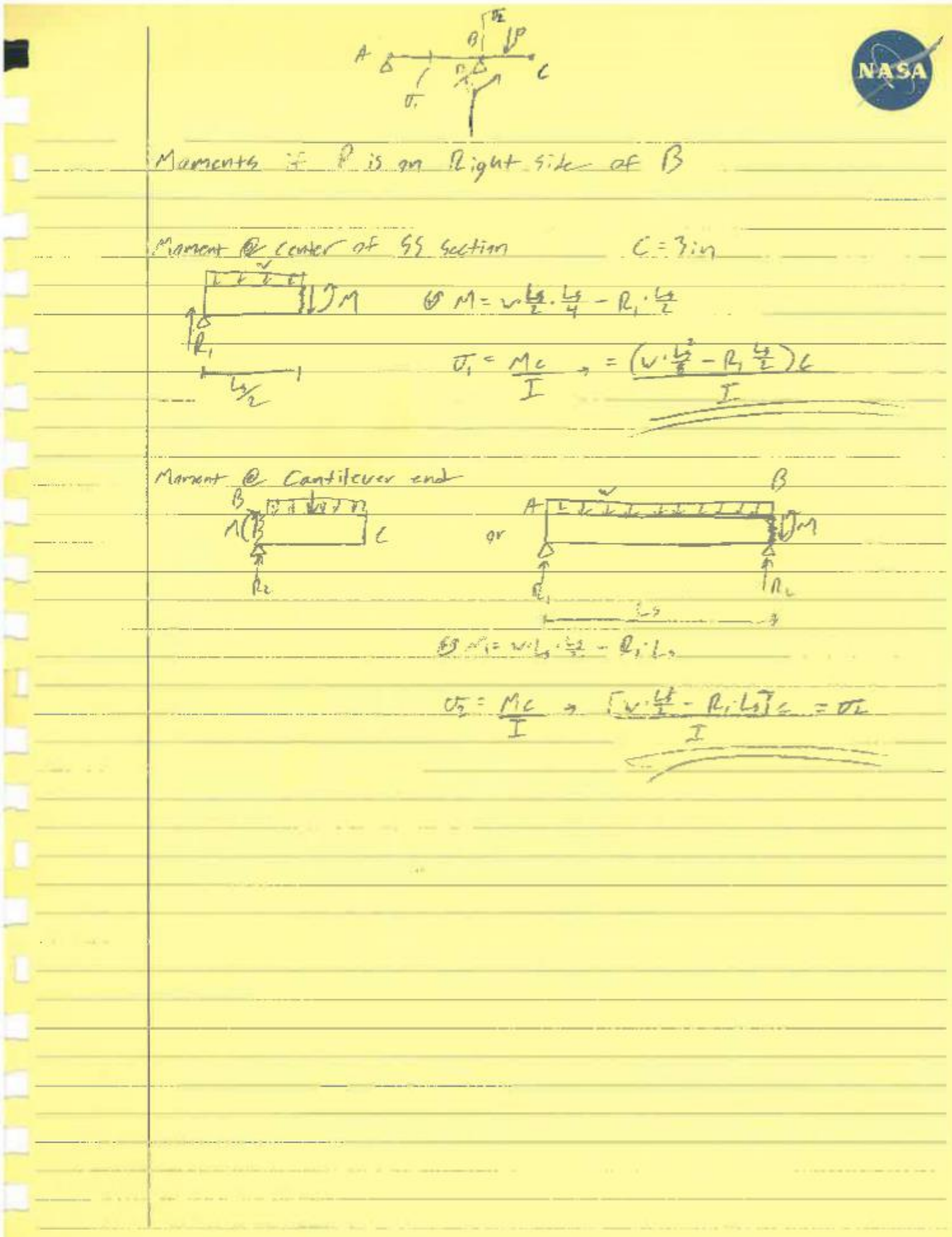


Figure 10-15: Hand Calculations

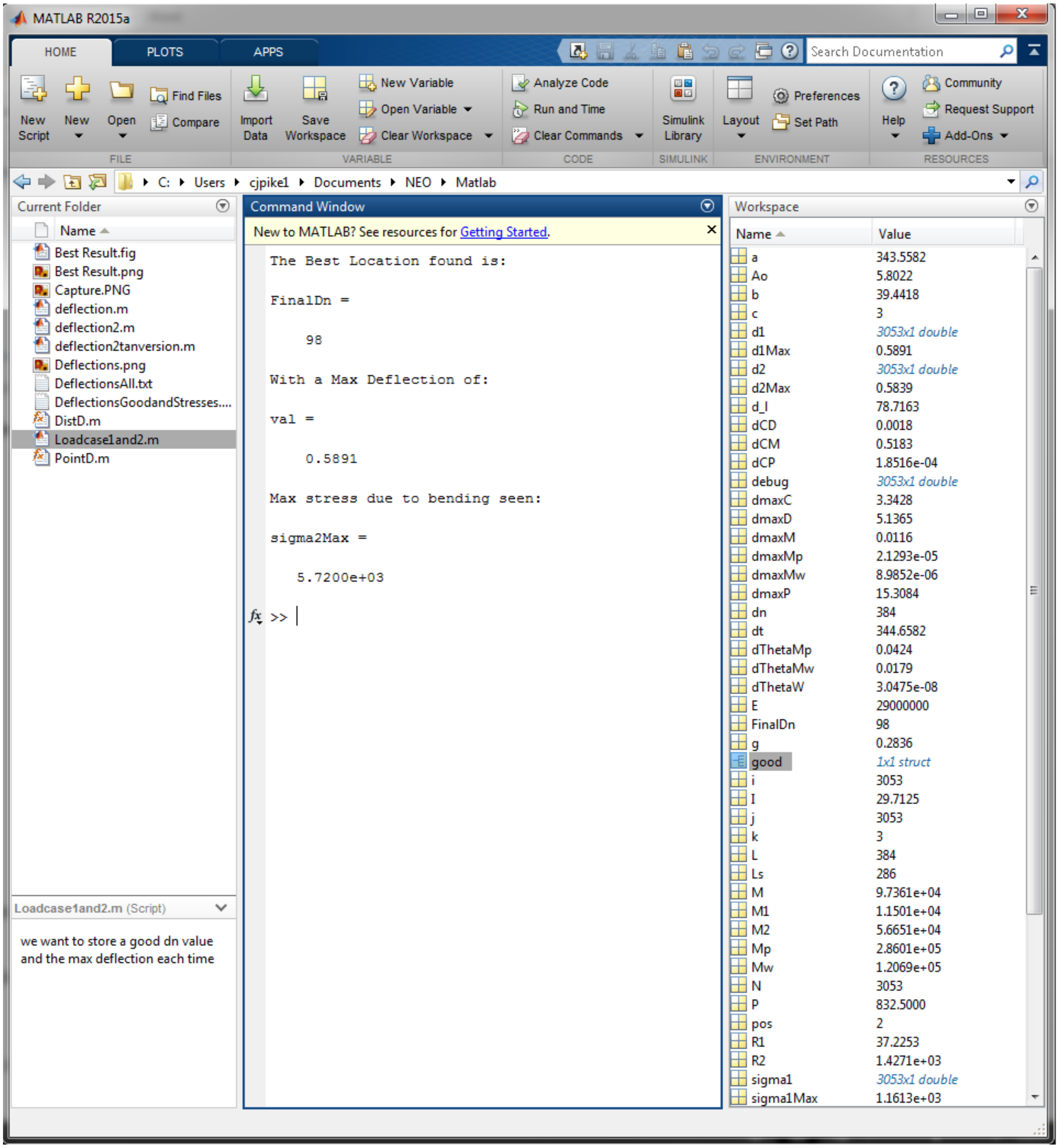


Figure X: Matlab Output

Loadcase1and2.m Matlab code

```
clear
clc

Step = 1;
SmallStep = 0.1;

L = 384;
Ao = 5.8022;     %Cross sectional area of beam
g = 0.2836;      %Specific weight of A992 Steel
```

```
c = 3;          %distance from neutral axis of beam cross section to edge

d_l = 78.7163;  %Distance between regolith loads

I = 29.7125;    %Moment of area for this W-beam
E = 29000*1000; %29,000 ksi = 29,000x10^3 psi
P = 1665/2;     %Simplified force, usually 1665/4
w = Ao*g;


N = (L-d_l)/SmallStep;
N = round(N);

M = L/Step;
dn = 1;
d1Max = 0;
d2Max = 0;
k = 1; %index for good support distances array (good.dn)
debug = zeros(N,1);

%we want to store a good dn value and the max deflection each time

for i = 1:M-1
    d1 = zeros(N,1);
    d2 = zeros(N,1);
    %Load will be positioned from 0 + dl/2 to L-dl/2 since the front of the
    %trough will be touching at 0+dl/2 and rear will touch the end at
    %L-dl/2

    dt = d_l/2;
    Ls = L-dn;
    debug(1) = dt;
    for j = 1:N

        if(dt<Ls)
            a = dt;
            b = L-dn-a;
            dmaxP = (P*b*(Ls^2 - b^2)^(3/2))/(9*sqrt(3)*Ls*E*I);
            dmaxD = (5*w*Ls^4)/(384*E*I);
            M = (w*dn^2)/2;
            dmaxM = (M*Ls^2)/(9*sqrt(3)*E*I);

            %solving for total deflection of left region (simply supported beam)
            d1(j) = dmaxP + dmaxD - dmaxM;
            %~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
            %this is math for right hand region
            thetaBP = (P*a*b*(2*Ls-b))/(6*Ls*E*I);
            dCP = tan(thetaBP)*dn;

            thetaBD = (w*Ls^3)/(24*E*I);
            dCD = tan(thetaBD)*dn;

            thetaBM = (M*Ls)/(3*E*I);
            dCM = tan(thetaBM)*dn;

            dmaxC = (w*dn^4)/(8*E*I);
            %solving for total deflection of the right region (cantelever beam)
            d2(j) = dCM + dmaxC - dCP - dCD;

        elseif(dt>Ls) && (dt<L)
            %Deflection of the left simply supported region
            dmaxD = (5*w*Ls^4)/(384*E*I);
            Mp = P*(dt-Ls);
```

```
            dmaxMp = (Mp*Ls^2)/(9*sqrt(3)*E*I);
            Mw = w*((dn^2)/2);
            dmaxMw = (Mw*Ls^2)/(9*sqrt(3)*E*I);

            %deflection for the center of the simply supported region
            d1(j) = dmaxD - dmaxMp - dmaxMw;
            %~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
            %this is math for right hand region
            %These are the slopes at the vertical support in the left
            %region. We use this to find how this affects the deflection of
            %the right region.
            thetaW = (w*Ls^3)/(24*E*I);
            dThetaW = dn*tan(thetaW);

            thetaMp = (Mp*Ls)/(3*E*I);
            dThetaMp = dn*tan(thetaMp);

            thetaMw = (Mw*Ls)/(3*E*I);
            dThetaMw = dn*tan(thetaMw);

            dmaxD = (w*dn^4)/(8*E*I);

            a = dt-Ls;
            b = dn-a;
            dmaxP = ((P*a^2)/(6*E*I))*(3*dn-a);

            d2(j) = dmaxP + dmaxD + dThetaMp + dThetaMw - dThetaW;

        end

        dt = dt + SmallStep;
        debug(j) = dt;
    end


    %for debugging only PLACE DEBUGGING BREAKPOINT AFTER THE PLOTS AND MAX
    clc
    max(abs(d1))
    max(abs(d2))

%     indexmax = find(max(abs(d1))==abs(d1));
%     xmax = debug(indexmax);
%     ymax = d1(indexmax);
%
%     indexmax2 = find(max(abs(d2))==abs(d2));
%     xmax2 = debug(indexmax2);
%     ymax2 = d2(indexmax2);
%
%     subplot(2,1,1)
%     plot(debug,d1)
%     title('Deflections in the Simply Supported Region (down is positive)')
%     xlabel('location down the beam from pad end (in)')
%     ylabel('Deflection (in)')
%     strmax = ['Maximum = ',num2str(ymax)];
%     text(xmax,ymax,strmax,'HorizontalAlignment','right');
%
%     subplot(2,1,2)
%     plot(debug,d2)
%     title('Deflections in the Cantilever region (down is positive)')
%     xlabel('location down the beam from the vertical support (in)')
%     ylabel('Deflection (in)')
%     strmax = ['Maximum = ',num2str(ymax2)];
%     text(xmax2,ymax2,strmax,'HorizontalAlignment','right');
```

```
    %need to check if the deflections were good enough to save!
    %if the max deflections of both sides are less than 0.5'' then we save
    %the position of the vertical support. Along with the max deflection
    %seen when running the load across the beam. This will be used to
    %compare later which vertical support position is most optimal.
    if(max(abs(d1))<0.6)&&(max(abs(d2))<0.6)
        good.dn(k) = dn;
        d1Max = max(abs(d1));
        d2Max = max(abs(d2));

        if(d1Max>d2Max)
            good.deltaMax(k) = d1Max;
        else
            good.deltaMax(k) = d2Max;
        end
        k = k+1;
    end

    dn = dn + Step;
end

%At this point we should have an array of good support positions and their
%corresponding max deflection.


if(exist('good')==0)
    disp('No good positions were found!')
else
    [val,pos] = min(good.deltaMax);

    FinalDn = good.dn(pos);

    disp('The Best Location found is:')
    FinalDn
    disp('With a Max Deflection of:')
    val

    %now to solve for the stresses due to bending with our new found position!
    sigma1 = zeros(N,1);
    sigma2 = zeros(N,1);
    dt = d_l/2;
    Ls = L-FinalDn;

    for i = 1:N
        if(dt<Ls)
            %stresses for both locations when load is applied before vertical
            %support
            R2 = (P*dt+w*L*(L/2))/(L-FinalDn);
            R1 = P + w*L - R2;

            sigma1(i) = ((w*(Ls/2)*(Ls/4)-R1*(Ls/2))*c)/I;
            sigma2(i) = ((w*((Ls)^2)/2 + P*(Ls-dt)-R1*Ls)*c)/I;
        elseif(dt>Ls) && (dt<L)
            %Stresses for both locations when load is applied after the
            %vertical support
            R2 = (w*((L^2)/2)+P*dt)/Ls;
            R1 = w*L + P - R2;

            M1 = w*(Ls/2)*(Ls/4)-R1*(Ls/2);
            M2 = w*Ls*(Ls/2)-R1*Ls;
```

```
            sigma1(i) = (M1*c)/I;
            sigma2(i) = (M2*c)/I;
        end

        dt = dt + SmallStep;
    end


    sigma1Max = max(sigma1);
    sigma2Max = max(sigma2);

    if(sigma1Max>sigma2Max)
        disp('Max stress due to bending seen:')
        sigma1Max
    else
        disp('Max stress due to bending seen:')
        sigma2Max
    end
end
```

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