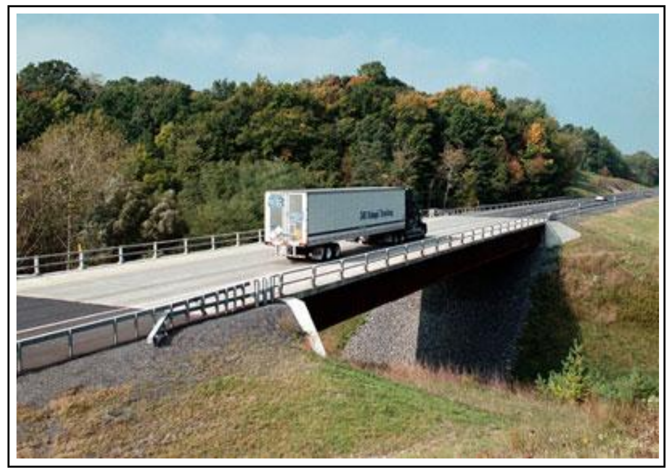
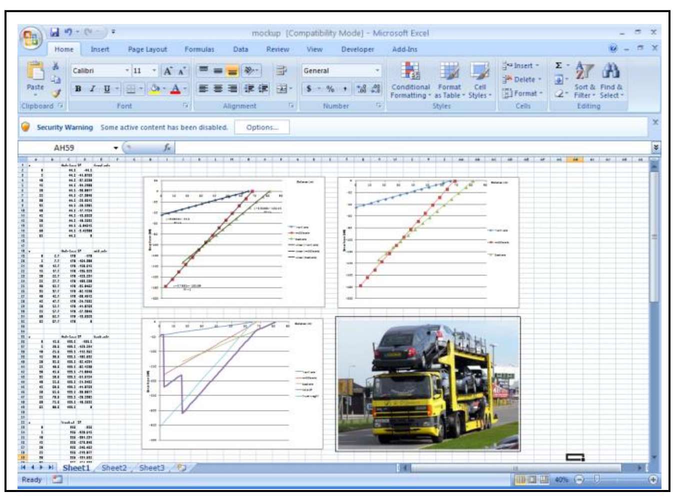
**EGS 2310 Engineering Analysis – Statics**

**Mock Term Project Report**

# TITLE:
# EVALUATING SHEAR FORCES ALONG HIGHWAY BRIDGES DUE TO TRUCKS, USING INFLUENCE LINES






**By**

**Kwabena Ofosu**

## Introduction

The impact of trucks on the structural integrity of bridges has become a particular issue of concern to State Departments of Transportation due to factors including:

a) Dwindling funding to sustain bridge maintenance programs in the current economic climate, and

b) Recent high profile catastrophic bridge failures such the Minnesota bridge collapse of September 2007 (Fig. 1), which received widespread media coverage, and generated new public and political interest in the state of our nation’s transportation infrastructure.

**Fig. 1: Bridge collapse, Minneapolis, MN, Sept 2007**

## Objectives

The objective of this presentation is to illustrate the effect of truck axle loads on a bridge span using influence lines to evaluate the shear force along the bridge span due to a truck at the legal weight limitation traversing it.

## Background Information

*Shear force* is the force in a beam acting perpendicular to its longitudinal (x) axis. Generally for design purposes, the ability to resist shear force is more important than its ability to resist an axial force, and is therefore a prime design criterion. Shear force at a point along a beam is computed by summing all vertical loads from a beam support to up to the point of interest. [Chapter 6]. A shear force diagram is a graphical representation of the magnitudes and directions of the shear force along the beam. [Chapter 6].

Note: Cover photographs were downloaded from wikipedia

An *influence line* is a graph of the variation of a function (such as the shear force, or bending moment felt in a structural member) at a specific point on the structure, caused by a unit load moving along the structure.

In this presentation the shear forces will be calculated based on a 3S2 combination vehicle, commonly called the "18 wheeler". This vehicle consists of a tractor semi-trailer combination with the tractor having 3 axles (1 single axle and 1 tandem axle) with a total of 10 tires, and the semi-trailer having 2 axles (or one tandem axle) with a total of 8 tires. Common regulations on the operations of such vehicles on US state highways that will be applied in this presentation include:

- Maximum length: 60 feet (18m)
- Maximum gross weight: 80,000 lb (356 kN)

An empty tractor trailer typically weighs in at approximately 20,000 lb (89 kN). In these computations it shall be assumed that the tractor weighs 20,000 lbs and the fully loaded semi-trailer weighs 60,000 lb

**Analysis**

The typical dimensions for the tractor semi-trailer combination used in this analysis are as shown in Fig. 2.

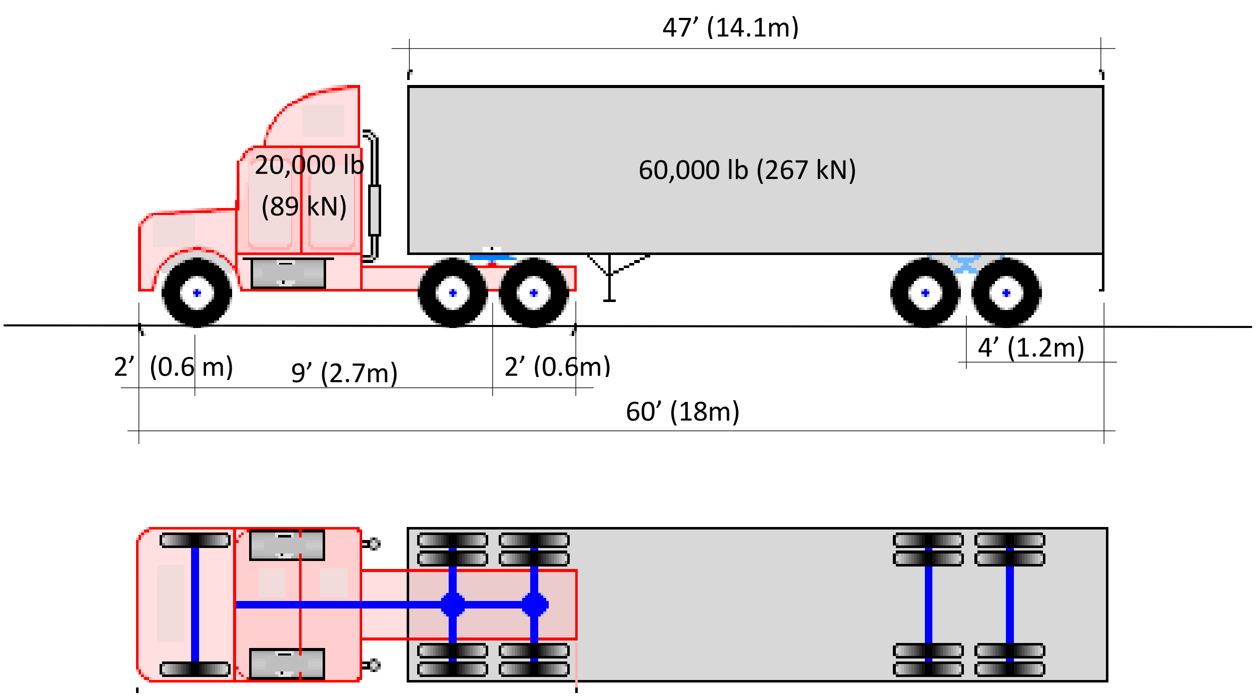



**Fig. 2: Tractor semi-trailer typical dimensions (Source: wikipedia)**

The first task of the analysis is to determine the normal reaction forces at the axles. The forces associated with these reactions are the actual forces that will be exerted on the bridge by the axles as the vehicle passes. The free body diagram of the truck is shown in Fig. 3.

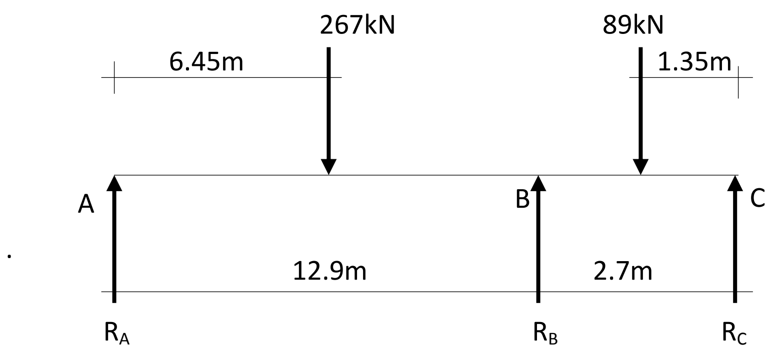


**Fig. 3: Free-body diagram of truck**

To solve for these reactions we shall apply the Equations of Equilibrium. The relevant equations will be

- summing vertical forces, and
- taking moment about a selected point.

This however results in a problem. The two equations will have a total of three unknowns, and cannot be solved, hence statically indeterminate structure. To overcome this problem it is assumed that the joint at which the tractor and semi-trailer are mated, is considered a hinge (Review topic Cables in Chapter 6). As a result moments can be taken about the hinge (summing to zero) resulting in a third equation, and the system of equations may now be solved.

The modified free body diagram will therefore be as shown in Fig. 4.

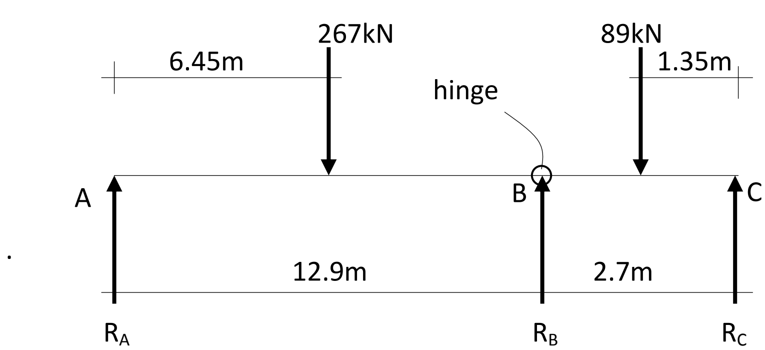


**Fig. 4: Modified free-body diagram of truck with hinged joint**

Summing moments about B (from the left hand side)

$$\sum M_B = 0$$

$$12.9R_A - 6.45(267) = 0$$

$$R_A = 133.5kN$$

Also, summing moments about B (from the right hand side)

$$2.7R_C - 89(1.35) = 0$$

$$R_C = 44.5kN$$

Summing vertical forces

$$\sum F_y = 0$$

$$133.5 + R_B + 44.5 = 267 + 89$$

$$R_B = 178kN$$

The next step is to draw the influence lines for the bridge reactions as a result of a point load traversing the bridge span. Consider a point load P = 1 kN moving across the bridge span. The free body diagram for the bridge when P is a distance *x* meters of the front axle from support A is as shown in Fig. 5, where L is the (longitudinal) bridge span length, P represent the axle load, and $V_A$ and $V_B$ are the normal reactions at the bridge span supports A and B respectively.

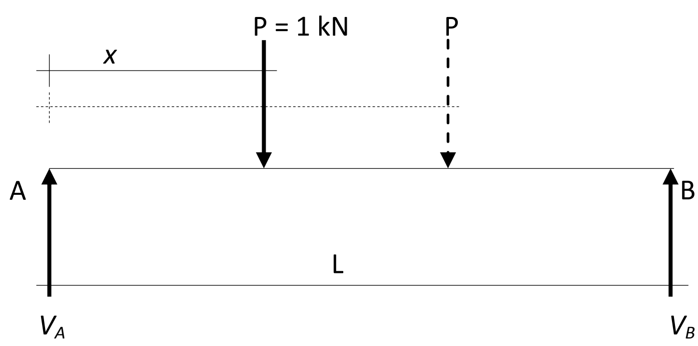



**Fig. 5: Free-body diagram of bridge**

Applying the Equations of Equilibrium

$$\sum M_B = 0$$

$$L.V_A - (L - x)P = 0$$

$$V_A = \frac{(L - x)P}{L} = 1 - \frac{x}{L}$$

$$\sum F_y = 0$$

$$V_B = P - V_A = 1 - \left(1 - \frac{x}{L}\right) = \frac{x}{L}$$

We may now compute the shear force at the location of the point load, a distance *x* (from A) along the bridge span of L = 65m. By definition, the shear force at a point is the sum of vertical from the right (or left) of the span up to the point of interest.

$\sum F_y$ from the right, shear force at a distance x from A ($SF_x$),

$$SF_x = V_B - P = \frac{x}{L} - P = \frac{x}{L} - 1 = \frac{x - L}{L}$$

For a non-unit point load *P* such as the loads on our truck axles,

$$SF_x = P\left(\frac{x - L}{L}\right)$$

We may now draw the graph of the shear force function for each axle as shown in Fig. 6.
Note that the shear force functions for the axles are horizontally displacement from each other by the distance of separation of the axles on the truck. Therefore as a result, for example, after the first axle has passed the bridge span, the middle axle and back axle continue to have impacts on the bridge.

The function of the total sheaf force as a result of all three axles of this vehicle on this bridge is obtained by adding the shear force functions of each axle along the bridge. The resulting function is called the shear envelope. The result is shown in Fig. 7.

Fig. 7 also show the shear force function if the truck had been represented as a single point load acting through its center of gravity rather than its individual axle loads. This method provides a general overview of the shear force impacts along the bridge however it is unable to accurately pinpoint the

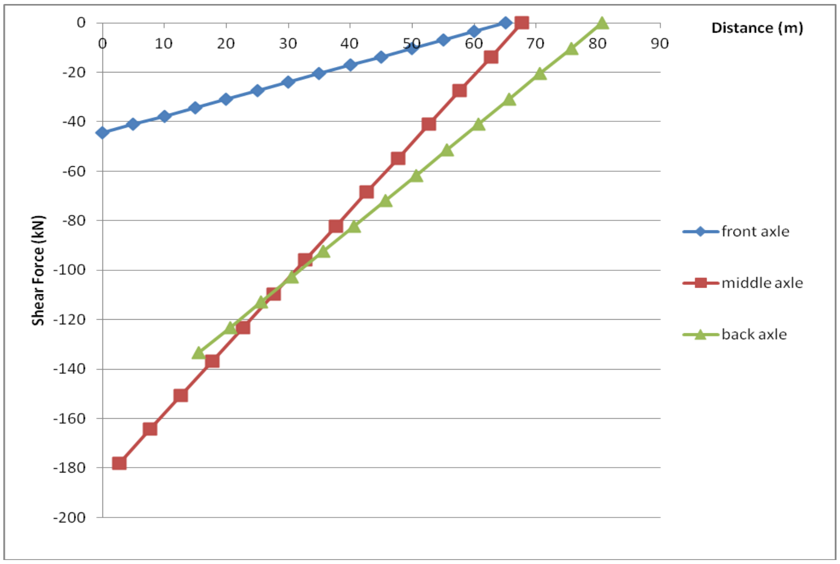



**Fig. 6: Influence lines for shear force due to truck axles**

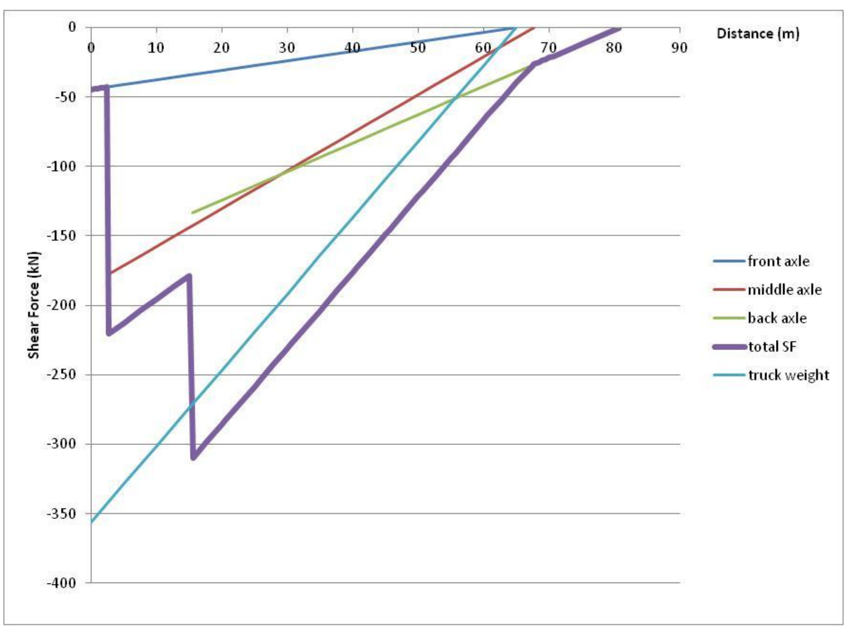



**Fig. 7: Shear envelope**

variations in shear force as the truck passes. As a result an engineer using it to analyze the structure would potentially be making incorrect conclusions and non-optimal decisions.

The analyses described in this section were implemented in *Visual Basic* computer program to facilitate rapid analysis of numerous scenarios. Details are provided in the Appendix.

**Conclusions**

This study applied influence lines to develop a methodology for evaluating shear force in a bridge span due to truck axle loads.

The methodology has been implemented as an off-the-shelf computer program an engineer can readily apply by adding the data for the specific design vehicle and bridge being studied.

The results confirmed that axle-by-axle analysis results in a more accurate prediction of shear forces on the bridge span.

**Recommendations For Further Study**

The perspective of the methodology demonstrated in this presentation was from that of assessing an existing bridge and looking at only the impacts of the truck axles. To be used for the design of new structures the methodology must incorporate factors such as self weight of bridge components such as the deck, concrete, asphalt, reinforcing steel and any and all other materials present on the structure or an integral part of it

This report looked at the effect of shear forces only. Shear force is one of several bridge design criteria. Other include bending moments, axial forces (compression, tension), deformation, cracking (in concrete bridges).

This report looked at one type of truck, the 3S2 tractor-trailer combination, commonly called the "18 wheeler". Future studies shall review other truck types and design vehicles used in several states and foreign countries.

The truck axle loading applied in this study were limited to the legal framework in Florida. Future study will investigate limitations in other state and national jurisdictions.

**Relevant Course Materials Applied In This Study**

- Dimensional Analysis (Units of Measure): Chapter 1
- Force Resultants: Chapter 2
- Equations of Equilibrium: Chapter 3
- Moments of Forces: Chapter 4
- Equilibrium of a Rigid Body: Chapter 5
- Structural Analysis: Chapter 6
- Internal Forces: Chapter 7

**References**

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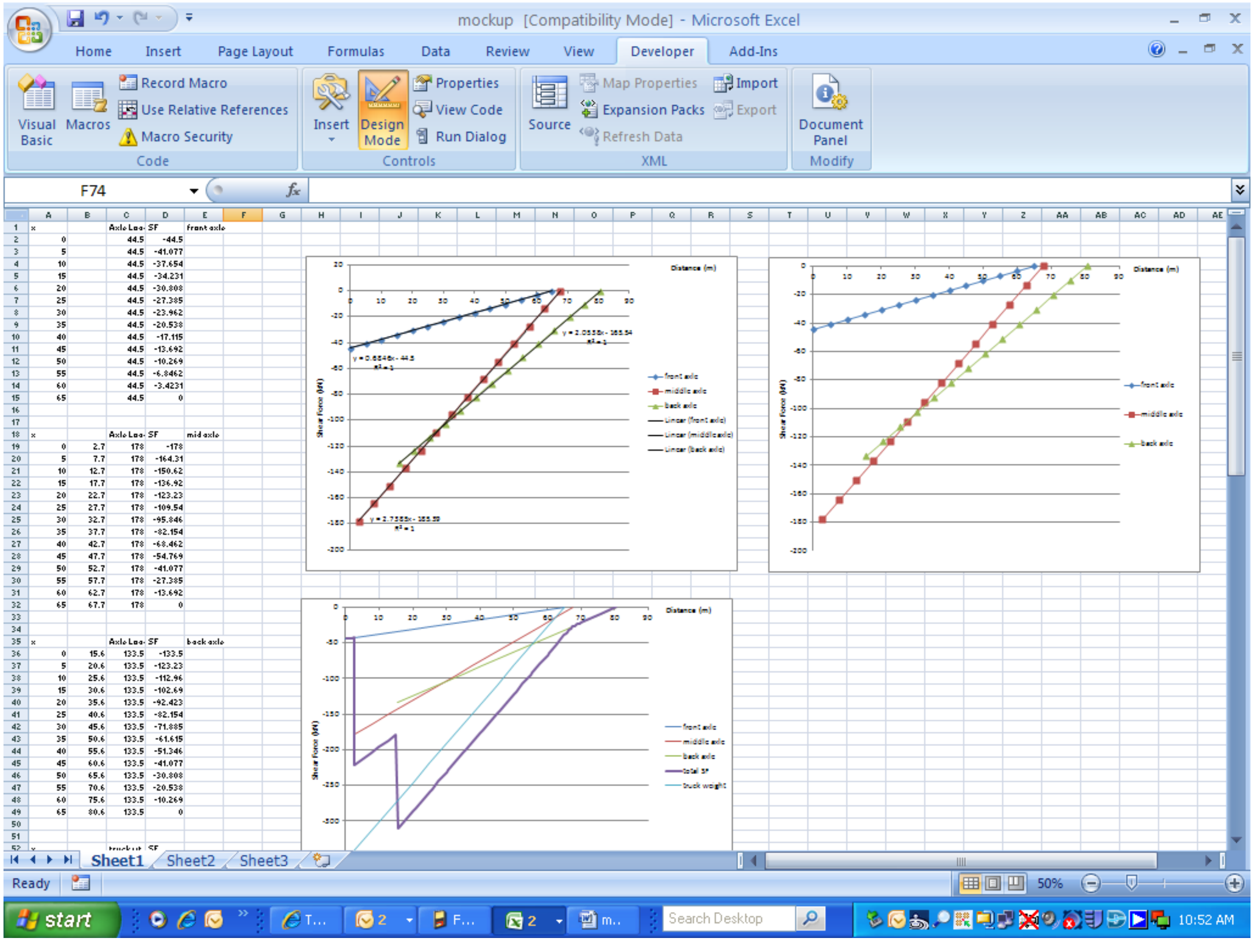
# Appendix



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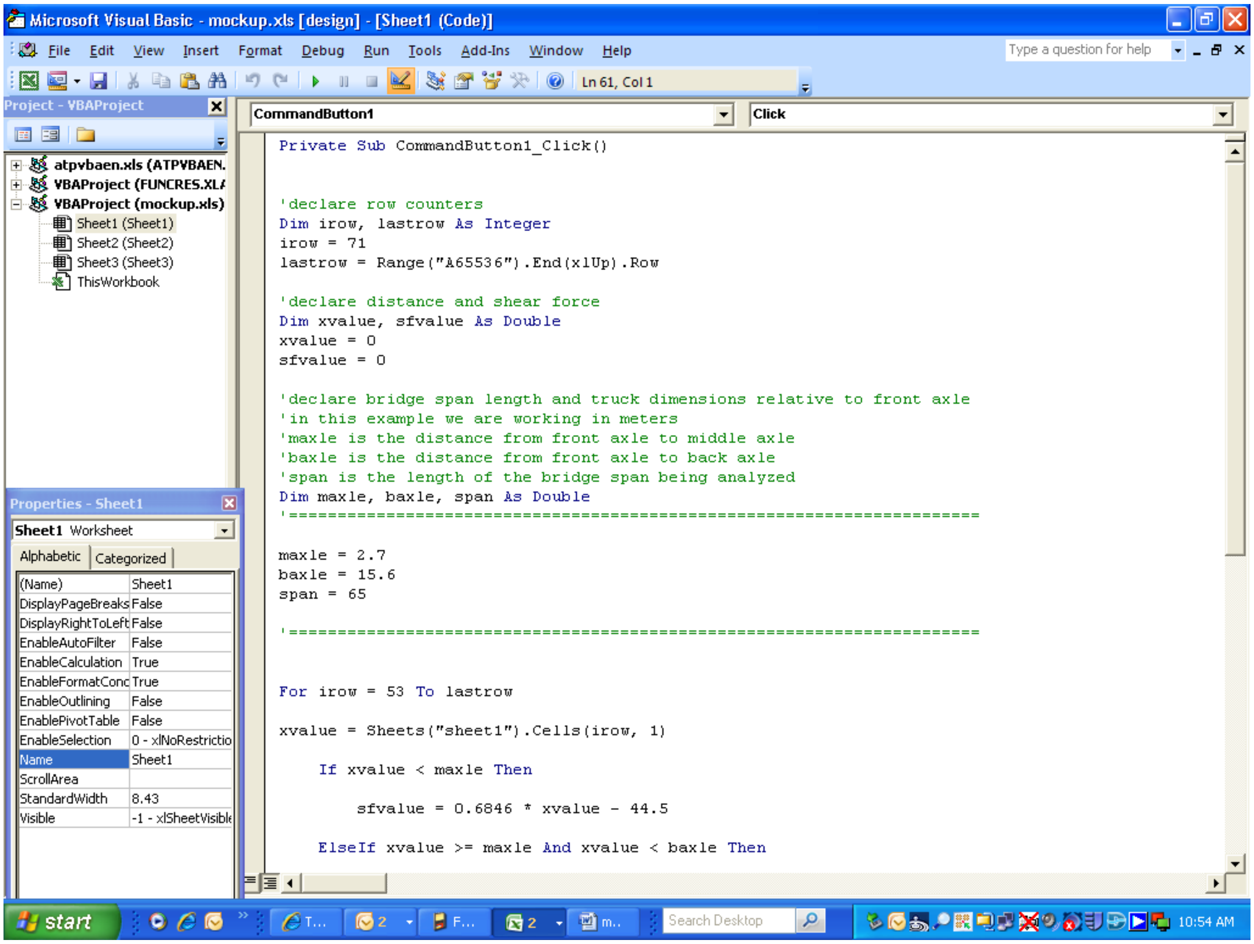
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DisplayPageBreaks False
DisplayRightToLeft False
EnableAutoFilter False
EnableCalculation True
EnableFormatConc True
EnableOutlining False
EnablePivotTable False
EnableSelection 0 - xlNoRestrictio
Name Sheet1
ScrollArea
StandardWidth 8.43
Visible -1 - xlSheetVisible
CommandButton1
Click
Private Sub CommandButton1_Click()
'declare row counters
Dim irow, lastrow As Integer
irow = 71
lastrow = Range("A65536").End(xlUp).Row
'declare distance and shear force
Dim xvalue, sfvalue As Double
xvalue = 0
sfvalue = 0
'declare bridge span length and truck dimensions relative to front axle
'in this example we are working in meters
'maxle is the distance from front axle to middle axle
'baxle is the distance from front axle to back axle
'span is the length of the bridge span being analyzed
Dim maxle, baxle, span As Double
'=====================================================================
maxle = 2.7
baxle = 15.6
span = 65
'=====================================================================
For irow = 53 To lastrow
xvalue = Sheets("sheet1").Cells(irow, 1)
If xvalue < maxle Then
sfvalue = 0.6846 * xvalue - 44.5
ElseIf xvalue >= maxle And xvalue < baxle Then
start
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