

*Full Length Research Paper*

# Visualizing the behaviour of reinforced concrete beam structure under various types of loadings

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This paper describes an approach to visualizing the detection of failure in Reinforced Concrete Beam Structure under various types of loadings. Several Reinforced Concrete Design (RCD) tools have been developed to support RCD, but there is little evidence that these solutions address the needs of the users. We studied RCD analysts' daily activities in order to understand their routine work practices and the need for designing RCD tools. Our approach is based on the principle of information visualization which has been applied in related fields. The Model-View-Controller (MVC) architecture is used to alleviate the black box syndrome associated with the study of algorithm behaviour for RCD for Beams. We propose a Visualization "exploratory" tool that assists the RCD designer in understanding the actual behaviour of the RCD Beam algorithms of choice and also in evaluating the performance quality of the algorithm. We demonstrate the feasibility of our approach using Simply Supported Reinforced Concrete Beam Structure (SSRCBS). We review Structural Analysis of Simply Supported Beam; our choice of design is governed by British Standard Code of Practice. VisRCD Beam Interface is created as our input visualization environment while borrowing and enhancing AutoCAD Interface as the output visualization environment. The analysis led to the development of a process model for SSRCBS work and related visualization needs. Our hypothesis testing reveals that RCD analyst will perform task and achieve acceptable results in less than 6½ min. The tool provides great benefit to the user by making their observations and judgement count.

**Key words:** Visualization, AutoCAD objects imported to VB.Net, state-of-the-art visualization, SSRCBS, VBA.

## INTRODUCTION

As organizational dependence on information technology and infrastructure increases, there is a correlated increase in the requirements for information assurance (Northcutt et al., 2000). Large-scale building failure is a critical national problem in Nigeria. Most of these failures were due to improper design of the building components such as foundation, column, beam, slab etc (Yusuf, 2004). The challenge of visually detecting failure during analysis before a final judgment is made for design is one of both great difficulty and utmost importance. Finding appropriate quantity of material for reinforced concrete structure at optimal cost presents an almost overwhelming task for RCD analysts. As Norman (1993) says, "the power of the unaided mind is highly overrated. Without external aids, memory, thought and reasoning all

are constrained. But human intelligence is highly flexible and adaptive, superb at inventing procedures and objects that overcome its own limits. The real powers come from devising external aids that enhance cognitive abilities. How have we increased memory, thought, and reasoning? By the invention of external aids: it is things that make us smart. According to Charles and James (2003), a structure will become unfit for use, if part or all of it collapses, but it will also become unfit if it deflects too much, if large cracks form or if vibration is so great that discomfort or alarm is caused to the occupants or the operation of machinery is interfered with.

The most important source of information for RCD analysts is the output. Due to the complicated nature of detecting actual status of failure during analysis and design of reinforced concrete structures, most current RCD tools place the burden of alert on the users by showing message alert and eventually terminating the program when a failure is envisaged or detected due to

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bad input/s. We believe this failure alert may be mitigated using information visualization RCD, which will take advantage of human perceptual abilities to amplify cognition. We conducted an exploration of the design space of RCD for SSRCBS via a field study of practicing analysts that identified several design implications. We also focus on the development of techniques and tools for the visualization of SSRCBS with the goal of aiding users in identifying failures at a point early enough in the attempt that user will not make a terrible judgement for design as not to cause failure to the proposed beam structure. This proposed rapid analysis and continuous monitoring are not possible with textual computational log information due to the time required to perform the analysis. This paper aims to improve the state of the art in this area.

## RELATED RESEARCH WORK

Little previous work has been done towards the use of visual analysis as an aid to RCD. For instance, Voicu and Christopher (2007) in his paper "Cad Visualization by Outsourcing" describe the production of high-quality visualizations of CAD scenes in state-of-the-art animation systems. He developed an importer in a relatively simple task which unlocks the many benefits of animation systems. Samir et al. (2000) introduces visual representation of structural concepts as a natural approach for students of architecture to promote structural intuition. His visual approach considers both visual examination and numerical analysis of the structural components. He observed that most engineering related areas that rely on computations that can be visually demonstrated are good candidates. The principal body of visualization work related to RCD is from Mohammed et al. (2005) in his paper "A Virtual Walkthrough on Reinforced Concrete Construction Details" In this project, he noticed that students in undergraduate engineering exhibit a stronger preference for the active, sensing visual and sequential learning styles which indicate that virtual reality can potentially have a tremendous impact on engineering education. Tony (2000) believes that the future educational programming environments should be visuals, he also observed that standard input and output is one of the most poorly visualized elements in commercial programming environments, he counselled that the input and output environment must be distinguished to be helpful to the users and the students alike. Lukas and Roddis (1996a, b) observed that for concrete structures typically found in practice, structural designers are faced with selecting good solutions from a set often too large to exhaustively search. Dealing with this large number of possibilities has traditionally been handled through a variety of rules-of-thumb, standard practices, iteration, and problem decomposition. This process has worked

reasonably well for many years, and has been incrementally improved through the use of commercial design tools. Most RCD interface has the ability to produce computational textual (tabular) output. Some have argued that data visualization simply substitutes for these tabular results, however, according to Chalmers and Chitson (1992), data graphics can do much more than simply substitute for tabular descriptions. At their best, graphics are instruments of reasoning about quantitative information. Often the most effective way to describe, explore, and summarize a set of numbers, even a very large set, is to look at pictures of those numbers. Graphical or visual presentations can not only describe data in different ways, but can also facilitate the comparison between different sets of data, stimulate scientific innovation, and even encourage theoretical insights. Information visualization consists of an appropriate transformation of input data to output graphics (Charles and James, 2003). Accordingly, it can be argued that a visualization method is acceptable, only if it clearly identifies the relevant information, defines an appropriate mapping, and generates the image accordingly. These three aspects are referred to as substance, design, and flow chart algorithm, respectively, which embody the general guidelines of RCD visualization. For Reinforced Concrete Design Structures, one view is often not sufficient to answer all interesting questions (William and Peter, 1994). Many views, each answering separate, but related questions, may work together to provide insight. The views should be tightly linked so that operations in one view, such as colour scale manipulations, propagate instantly to the other views. Together, the combination of several simple views is much more powerful than the sum of the individual views taken one at a time. According to Collin (2004), human attention is a very limited resource. If it is taken up with irrelevant visual noise, or if the rate at which visual information is presented on the screen poorly matches the rate at which people can process visual patterns, then the system will not function well. Collin believed that there are two fundamental ways in which visualization support thinking, first by supporting visual queries on information graphics, and second by extending memory. Memory provides the framework that underlies active cognition, whereas attention is the motor. Pirolli and Card (1995) drew an analogy with the way animals seek food to gain insights to about how people seek information. Animals minimize energy expenditure to get the required gain in sustenance; humans minimize effort to get the necessary gain in information. Foraging for food has much in common with the seeking of information because, like edible plants in the wild, morsels of information are often grouped, but separated by long distances in an information wasteland. Pirolli and Card elaborated the idea to include information "scent" – like the scent of food, this is the information in the current environment that will assist us in finding more succulent information

clusters. Mike and Alexander (2002) in "The Data Visualization Environment," present the issues for the development of visualization and interaction techniques within exploration environments. Discussions include the requirements for supporting users and the possible addition of computer-assisted techniques. John (2002: 9) in "Portable Document Indexes," believes visualization should be a means of involving the user in a search for results, rather than creating visualizations to present results to the user. Vasu et al., (1997) observed that computer has gained efficiency with less cost, it can be used to calculate and design reinforced concrete structures, he believes the manual method to calculate and design reinforced concrete structures is likely to create error due to complex calculation process and human error unless computer program is apply in this area. Fatima (1992) reiterated the fact that an important objective of structural engineering is to produce artefacts that are safe and reliable. She considered a model of design process for civil engineers and believe such a model should be consistent at all levels, make use of new knowledge as it evolves and preferable be able to produce explanation. Simon (1969) defines design as a problem solving activity. He summarized problem solving as the process of finding solutions in a problem space, which represents possible states of the problem (that is possible problem descriptions) to be considered in attempting a solution. Remo (2005) observed that the fact that information is available does not automatically mean that it is also used, shared, or understood. He believes the effective transfer of knowledge is becoming a key-challenge in today's activities for professionals, and it is also a key in design process oriented knowledge infrastructures. He considered different enquiries to be made, such as: Who are the audience? What are the cultural, functional, or educational backgrounds of the recipients? Why is the information relevant to the individual recipients? Is the audience interested in an overview or in details? What are strategies to overcome the limited capacities of the listeners, such as limited time, attention, or mental capacity?

Collin (2004) highlighted a number of the advantages of visualization and proposed four stages for visualization as follows: The collection and storage of data itself, The pre-processing designed to transform the data into something we can understand, The display hardware and the graphics and graphics algorithms that produce an image on the screen, The human perceptual and cognitive system (the perceiver). Ronald and Georges (2002) discuss the need for "Evaluation of Visualization Systems" The need to determine quantitatively the relative merits of competing displays or systems and to be able to tell, when to adjust parameters, whether a display or system has been made better or worse is very important. He believes that the current approach to evaluation and enhancement of visualization displays and visualization systems is largely a matter of qualitative

judgment of how trial and error in efforts to do better is doing. Folorunso (2003) described Real Time Database System (RTDBS) as the mainstream of computer operations which aptly described as a system that produces result in a timely and consistent fashion. From the result gathered, he observed that the RTDBS designers are interested in seeing how their algorithms behaved, he then proposed an extendable framework using Model-View-Controller paradigm. Owolabi (2005) proposed a visualization framework which has good extensibility for plugging in new data sources, supporting new data models, visual presentation types and allowing new graph layout algorithms. He presented the tool as an aid to academic research and teaching in the field of relational database systems and in practice to help database developers compare different solutions for database schemes with respect to normalization. Fady and Rostom (2003) reiterated the fact that the work of a civil engineer requires a lot of precision. This is mainly due to the fact that the final result of any project will directly or indirectly affect people's lives; hence safety becomes a critical issue. Designing structures and developing new facilities may take up to several months to complete. The volumes of work, as well as the seriousness of the issues considered in project planning, contribute to the amount of time required to complete the development of an adequate, safe and efficient design. He then suggested the usage of software in the civil engineering industry to reduce the complexities of different aspects in the analysis and design of projects, as well as reducing the amount of time necessary to complete the designs so as to enhance greater savings and reductions in costs. Yusuf (2004) believes complex projects that were almost impossible to work out several years ago are now easily solved with the use of computers. In order to stay at the pinnacle of any industry, one needs to keep at par with the latest technological advancements which accelerate work time frames and accuracy without decreasing the reliability and efficiency of the results. According to Bill et al. (2007) a satisfactory and economic design of a concrete structure rarely depends on a complex theoretical analysis. It is achieved more by deciding on a practical overall layout of the structure, careful attention to detail and sound constructional practice. The total design of a structure does depend on the analysis and design of the individual member sections. He counsel that the design and detailing of the bending reinforcement must allow for factors such as anchorage bond between steel and concrete. Donald (2002) defined design as a complex endeavour. Donald was concerned with how well design fits the needs of the people who use it, he believes whenever we have trouble with our tool, it is not our fault, it is the fault of the design and we should not blame ourselves. He wants us to make it a rule never to criticize something unless we can offer a solution. He felt the surest way to make something easy to use, with errors, is

**Table 1.** Study methods and SSRCBS domain expert participants.

Method	No. of RCD analysis	No. of non-professional RCD	Total No. of Participants
Prototype evaluation	10	10	20
Contextual interviews	1-	1-	20
Focus group	10	0	10

to make it impossible to do otherwise that is, to constraint the choice. In his word, “a good designer makes sure that appropriate actions are perceptible and inappropriate ones invisible”. Gould and Lewis (1985) in their work on human-oriented system design posited three principles of a UCD. The three principles are: An early focus on users and tasks, Empirical measurement of product usage, Iterative designs whereby a product is designed, modified, and tested repeatedly. Folorunso et al. (2008) describes an approach to visualizing concurrency control (CC) algorithms for real-time database systems (RTDBs). The approach was based on the principle of software visualization; they employed Model-View-controller (MVC) architecture to alleviate the black box syndrome associated with the study of algorithm behaviour for RTDBs Concurrency Controls. They also proposed a Visualization “exploratory” tool that assists the RTDBS designer in understanding the actual behaviour of the concurrency control algorithms of choice and also in evaluating the performance quality of the algorithm. They demonstrated the feasibility of their approach using an optimistic concurrency control and they eventually use the tool to solve the problem of contradictory assumptions of CC in RTDBs. Folorunso and Ogunseye (2008) investigates the applicability of Davis’s Technology Acceptance Model (TAM) to agriculturist’s acceptance of a knowledge management system (KMS), they were able to discern that significant positive relationships between perceived usefulness, ease of use, and system usage were consistent with previous TAM research.

## METHODOLOGY

The sample for the study was comprised of ten RCD professional analysts and ten computer enthusiast that are not RCD skilled as shown in Table 1. The Twenty participants also volunteered for a prototype evaluation. By deliberately choosing a sample with diverse experience in different professions, the range of viewpoints represented was increased.

Model-View-Controller concept was used to implement the SSRCBS tool. The Model is embedded in various pseudo codes and converted into VB.Net language which works at the background; it maintains both input and output of our data. The View is the VisRCD input interface, Legend interface, editor interface and the AutoCAD interface that displays all or portion of our data. The Controller is the various buttons, menus and sub-menus which help in the manipulation of our model to achieve the desire results; it handles all events that affect the model or views.

## Analysis of simply supported beams

Beams simply supported at both ends and carrying various types of loads as shown in Figure 1, are analysed for Shear Force (S.F.) and Bending Moment (B.M.). Four types of Loadings were considered for the purpose of this paper. The loads can be superimposed to form a new load up to 4<sup>2</sup> ways. For example, uniformly distributed load (UDL) can be combined with a right-angled triangular load (UDRTL) to form a trapezoidal load.

For the design of most reinforced concrete structures it is not unusual to commence the design for the conditions at ultimate limit state, that is, determine the Dead Load or Permanent Load (DL), Live Load or Imposed Load or Variable Load (LL) and probably Wind Load (WL) in case of building structure up to five storey and applying adequate factor of safety, which is then followed by checks to ensure that the structure is adequate at the serviceability (deflection, cracking, durability, excessive vibration, fatigue and fire resistance). For Limit State Design, the partial factor of safety applies to Dead and Live Load is 1.4 and 1.6 respectively.

### Concentrated Load or Knife Edge Load not at the Mid Span is divided into Knife Edge Dead Load (KEDL) and Knife Edge Live Load (KELL):

$$\text{Ultimate Knife Edge Load (UKEL)} = (1.4 * \text{KEDL}) + (1.6 * \text{KELL})$$

The Ultimate Knife Edge load is used to calculate Ultimate Moment (M) and Ultimate Shear Force (SF) along the Beam. The Maximum Moment and Maximum Shear Force is of most interest to RCD designer, but for the purpose of drawing the Bending Moment and Shear Force diagram it is necessary to determine the ultimate moment and ultimate shear force at every section of the beam section as follows;

Assume UKEL is at distance ‘a’ from the left support (LEFTSUPPORT), it is therefore implies that UKEL will be at distance ‘Length – a’ from right support (RIGHTSUPPORT).

$$\begin{aligned} \text{SF at LEFTSUPPORT} &= \text{UKEL} * (\text{Length} - a) / \text{Length} \\ \text{SF at RIGHTSUPPORT} &= \text{UKEL} * a / \text{Length} \end{aligned}$$

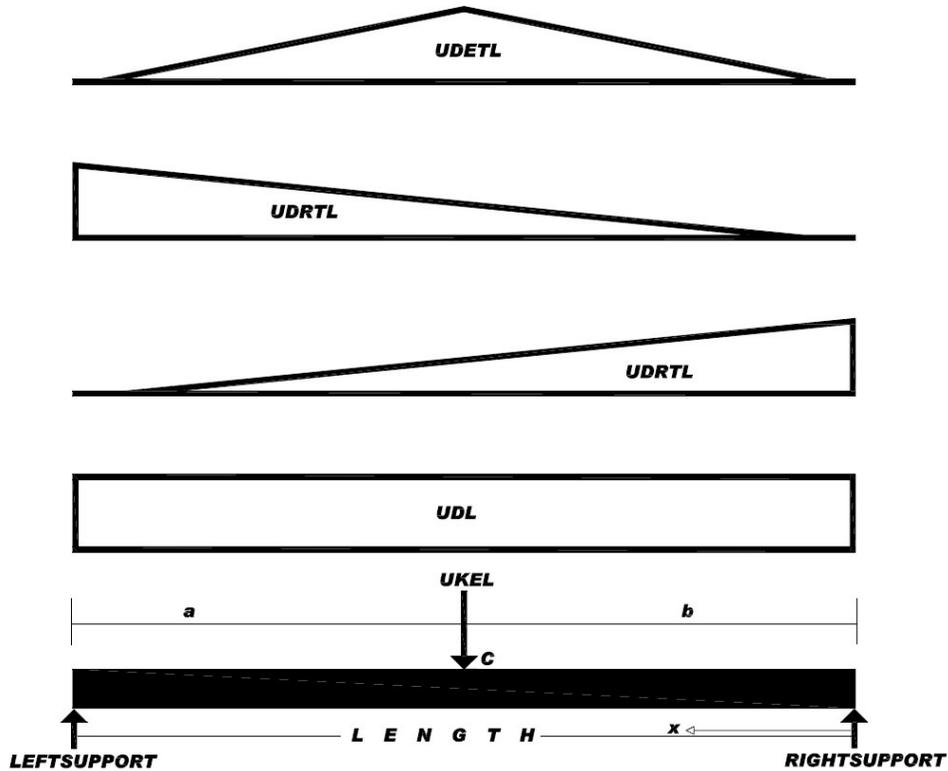


Figure 1. Ultimate load on beam.

Maximum moment,  $M = UKEL * a * (Length - a) / Length$

**Uniformly Distributed Load (UDL) over the entire span:**

$$UDL = (1.4 * DDLL) + (1.6 * DLLL).$$

DDLL is the Distributed Dead Linear load while DLLL is the Distributed Live Linear Load SF at a section at a distance x from RIGHTSUPPORT is  $F_x = +UDL * Length / 2 - UDL * x$

Where;  $0 \leq x \leq Length$

B.M. at the section is  $M_x = +1/2 * UDL * Length * x - 1/2 * UDL * x^2$

$x = Length / 2$  for the B.M. to be maximum (it should be noted that the S.F. is zero at this point).

$$M_{max} = +UDL * Length^2 / 8$$

**Varying Load from zero at one support to w kg/m at the other support:**

$$UDRTL = (1.4 * DDLR) + (1.6 * DLLR)$$

UDRTL is the Ultimate load for Right-Angled triangular load spreading over the entire span DDLR is the Distributed Dead load while DLLR is the Distributed Live

load SF at section x is

$$F_x = UDRTL * x^2 / (2 * Length)$$

S.F. at RIGHTSUPPORT where  $x = 0$  is  $+ UDRTL * Length / 6$

S.F. at LEFTSUPPORT where  $x = Length$  is  $- UDRTL * Length / 3$

S.F. is zero when  $UDRTL * Length / 6 - UDRTL * x^2 / (2 * Length) = 0$

$$\text{Or } x = Length / (3)^{1/2}$$

B.M. at the section is

$$M_x = UDRTL * Length * x / 6 - UDRTL * x^2 / (6 * Length)$$

B.M. is maximum when

$$dM_x/dx = UDRTL * Length / 6 - UDRTL * x^2 / (2 * Length) = 0$$

$$\text{or } x = Length / (3)^{1/2} \text{ (here S.F. is zero)}$$

$$M_{max} = UDRTL * Length^2 / (9 / (3)^{1/2})$$

**Varying Uniformly Load from zero at either ends to w kg/m at Mid-Span:**

$$UDETL = (1.4 * DDLT) + (1.6 * DLLT)$$

UDETL is the Ultimate load on beam varying from zero at either ends to w kg/m at mid-span

DDLT is the Distributed Dead load while DLLT is the Distributed Live load Therefore S.F. at section x is

$$F_x = + UDETL * Length / 4 - UDETL * x^2 / Length$$

S.F. at RIGHTSUPPORT where  $x = 0$  is  $+ UDETL * Length / 4$

S.F. at C where  $x = Length / 2$  is  $F_c = + UDETL * Length / 4 - UDETL / Length * (Length / 2)^2 = 0$

S.F. at LEFTSUPPORT is  $- UDETL * Length / 4$

$M_x = UDETL * Length * x / 4 - (2 * UDETL * x / Length * x / 2) * x / 3$

B.M. is zero at both the LEFTSUPPORT and RIGHTSUPPORT since the beam is simply supported.

For the B.M. to be maximum we have;

$dM_x/dx = UDETL * Length / 4 - UDETL * x^2 / Length = 0$

$x = Length / 2$  (here the S.F. is zero)

The maximum B.M. is thus at mid-span and is ;

$M_{max} = +UDETL * Length^2 / 12$

### Design of beam to British standard (BS) code 8110 of practice

Due to space limitation, we provide extract of our pseudo code in order to comprehend the process involved in the design of Reinforced Concrete Beam Structures. The pseudo codes were coded in Object Oriented Language using VB.Net to achieve the desired performance of our tool. The four loads are assumed to act on the beam simultaneously. Any load not in context will take a default value of zero; this makes our analysis and coding easier. For example, total Ultimate Moment on beam is the algebraic sum of Moments due to the four amalgamations; same applies to Ultimate Shear Force.

The layout and size of beam members are very often controlled by architectural details, and clearances for machinery and equipment. The engineer must either check that the beam sizes are adequate to carry the loads, or alternatively, decide on sizes that are adequate. Our analysis above serves as input and provides the maximum moments and shears in order to ascertain reasonable dimensions. Beam dimensions required for design are shown in Figure 2.

For ease of understanding of the pseudo code, we shall assume that;

$h \rightarrow$  Beam\_height

$d \rightarrow$  Beam\_Depth

cover  $\rightarrow$  Concrete\_Cover

$t \rightarrow$  Diameter\_Of\_Stirrup +  $1/2$  Diameter\_Of\_Main\_Steel

$b \rightarrow$  Beam\_Width

The few of the steps involved in the design of RCD for Beams are presented in pseudo code below:

### Algorithm for design of beam

Main

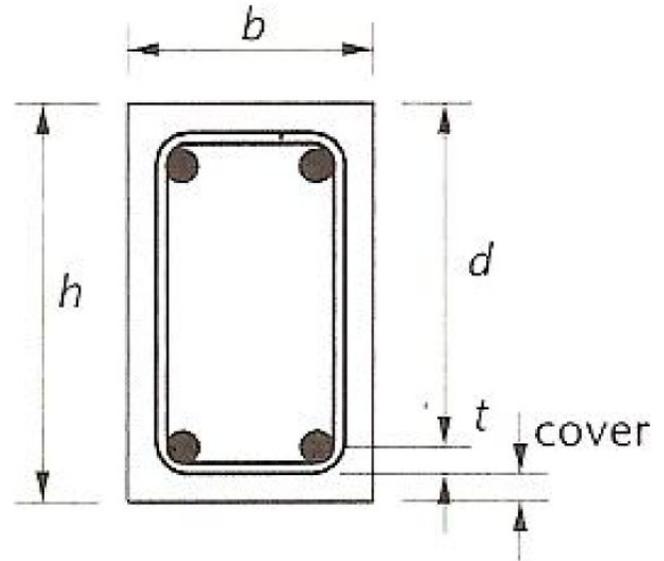


Figure 2. Rectangular beam section and dimension.

Begin

Comment: Area\_Of\_Steel\_In\_Beam

Input Concrete\_Strength, Beam\_Width, Beam\_Height,

Concrete\_Cover, Diameter\_of\_Main\_Steel

Input Diameter\_of\_Stirrup, Steel\_Strength

Call Procedure Get\_Beam\_Load

Declare Ultimate\_Moment = (Ultimate\_Knife\_Edge\_Load \*  
\*

Distance\_of\_Knife\_Edge\_Load\_From\_Left\_Support \*

(Length\_of\_Beam -

Distance\_of\_Knife\_Edge\_Load\_From\_Left\_Support) /

Length\_of\_Beam + Ultimate\_Distributed\_Load \*

Length\_of\_Beam<sup>2</sup> / 8 +

Ultimate\_Distributed\_RightAngledTriangle\_Load \*

Length\_of\_Beam<sup>2</sup> / (9 / (3)<sup>1/2</sup>) +

Ultimate\_Distributed\_EquilateralTriangular\_Load \*

Length\_of\_Beam<sup>2</sup> / 12)

Declare Beam\_Depth = Beam\_Height - Concrete\_Cover

- Diameter\_Of\_Stirrup -  $1/2$  Diameter\_Of\_Main\_Steel

Declare Moment\_of\_Resistance = 0.156 \*

Concrete\_Strength \* Beam\_Width \* Beam\_Depth<sup>2</sup>

If Ultimate\_Moment  $\leq$  Moment\_of\_Resistance

Do Call Procedure Singly\_Reinforced

Else Do Call Procedure Doubly\_Reinforced

End If

Call Procedure Check\_For\_Shear

Call Procedure Check\_For\_Deflection

End

Procedure Get\_Beam\_Load

Begin

Input Length\_of\_Beam,

Distance\_of\_Knife\_Edge\_Load\_From\_Left\_Support

Input Knife\_Edge\_Dead\_Load, Knife\_Edge\_Live\_Load

Input Distributed\_Dead\_Linear\_Load,

Distributed\_Live\_Linear\_Load

```

Input Distributed_Dead_Load_RightAngledTriangular,
Distributed_Live_Load_RightAngledTriangular
Input Distributed_Dead_Load_EquilateralTriangle,
Distributed_Live_Load_EquilateralTriangle
Declare Ultimate_Knife_Edge_Load = (1.4 *
Knife_Edge_Dead_Load + (1.6 * Knife_Edge_Live_Load)
Declare Ultimate_Distributed_Load = (1.4 *
Distributed_Dead_Linear_Load + (1.6 *
Distributed_Live_Linear_Load)
Declare Ultimate_Distributed_RigthAngledTriangle_Load
= [(1.4 * Dead_Load_RightAngledTriangular) + (1.6 *
Distributed_Live_Load_RightAngledTriangular)]
Declare Ultimate_Distributed_EquilateralTriangular_Load
= [(1.4 * Distributed_Dead_Load_EquilateralTriangle) +
(1.6 * Distributed_Live_Load_EquilateralTriangle)]
End

```

Procedure Singly\_Reinforced

```

Begin
Declare k = Ultimate_Moment / (Concrete_Strength *
Beam_Width * Beam_Depth2)
Declare Lever_Arm = Beam_Depth * (0.5 + sqrt (0.25 – k
/ 0.9)
If Lever_Arm ≤ 0.95 * Beam_Depth
Do Lever_Arm = Lever_Arm
Else
Do Lever_Arm = 0.95 * Beam_Depth
End If
Declare Area_of_Tension_Steel = Ultimate_Moment /
(0.95 * Steel_Strength * Lever_Arm * Beam_Depth)
Call Procedure
Take_Minimum_Maximum_Area_of_Steel_In_Beam_Dec
ision
End

```

Procedure Doubly\_Reinforced

```

Begin
Declare k_prime = Moment_of_Resistance /
(Concrete_Strength * Beam_Width * Beam_Depth2)
z = Beam_Depth * (0.5 + sqrt (0.25 – k_prime / 0.9))
x = (d – z) / 0.45
Declare Area_of_Compression_Steel =
[(Ultimate_Moment – Moment_of_Resistance) /
((0.95 * Concrete_Strength) * (Beam_Depth –
Concrete_Cover – Diameter_Of_Stirrup)]
Declare Area_of_Tension_Steel =
Moment_of_Resistance / (0.95 * Steel_Strength * z) +
Area_of_Compression_Steel
Call Procedure
Take_Minimum_Maximum_Area_of_Steel_In_Beam_Dec
ision
End

```

Procedure

```

Take_Minimum_Maximum_Area_of_Steel_In_Beam_Dec
ision
Begin

```

```

If Mild_Steel
Call Procedure Check_For_Area_of_Mild_Steel
Else
Call Procedure Check_For_Area_of_Highyield_Steel
End If
End

```

Procedure Pick\_Main\_Bar\_From\_Steel\_Table

```

Begin
Label 1: For Diameter_Of_Main_Steel = 8 to 40 Step 2
For Number_of_Steel = 1 to 10
If Diameter_of_Main_Steel = 26
Do Diameter_of_Main_Steel = Diameter_of_Main_Steel -
1
End If
If Area_of_Tension_Steel > Area_of_Steel_in_Table
Do Diameter_of_Main_Steel = Diameter_Of_Main_Steel
+ 2
Goto Label 1
Else Do
Area_of_Steel_in_Table = Area_of_Steel_in_Table
End If
Return Number_of_Steel, Diameter_of_Main_Steel,
Area_of_Steel_in_Table
End

```

Procedure Check\_For\_Shear

```

Begin
Declare Shear_Stress = Shear_Force / (Beam_Width *
Beam_Depth)
If (100 * Area_of_Tension_Steel) / (Beam_Width *
Beam_Depth) ≥ 3
Do (100 * Area_of_Tension_Steel) / (Beam_Width *
Beam_Depth) = 3
End If
If (400 / Beam_Depth) ≥ 1
Do 400 / Beam_Depth = 1
End If
Declare Design_Shear_Stress = (0.632 * (100 *
Area_of_Tension_Steel /
(Beam_width * Beam_Depth)) ^ 1/3 * (400 /
Beam_Depth) ^ 1/4)
If Shear_Strees < 0.5 * Design_Shear_Stress
Do provide minimum link that is, 10mm @ 300mm c/c or
Sv = 0.7 * Beam_Depth, whichever is smaller
Else Do
If (0.5 * Design_Shear_Stress < Shear_Stress <
(Design_Shear_Stress + 0.4)
Do Sv = 0.95 * Steel_Strength * Asv / (0.4 * Beam_Width)
Else Do
If (Design_Shear_Stress + 0.4) < Shear_Stress < 0.8 *
sqrt (Concrete_Strength) or _
(Design_Shear_Stress + 0.4) < Shear_Stress < 5
Do Sv = 0.95 * Steel_Strength * Asv / (Beam_Width *
(Shear_Stress – Design_Shear_Strength))
Else Do
If Shear_Stress > 0.8 * sqrt (Concrete_Strength) or

```

```

Shear_Stress > 5
Do msg: increase depth of Beam
End If
End If
End If
End If
Call Procedure Design_Stirrup
End

Procedure Check_For_Deflection
Begin
Input Length_Of_Beam, Span_Effective_Depth_Ratio =
20
Declare Fs = 2 * Steel_Strength *
Area_Of_Steel_In_Table / (3 * Area_Of_Tension_Steel)
Declare Modification_Factor = 0.55 + (477 - Fs) / (120 *
0.9 + Ultimate_Moment / (Beam_Width * Beam_Depth2))
If Modification_Factor ≥ 2
Do Modification_Factor = 2
End If
Declare Actual_Depth_Required = Length_of_Beam /
(Modification_Factor * Span_Effective_Depth_Ratio)
If Actual_Depth_Required > Beam_Depth
Do msg: Deflection criteria not satisfied
Else Do
If Ultimate_moment ≤ Moment_of_Resistance
Do Msg: Deflection Criteria is satisfied
Else Do
Declare Modification_Factor_For_Compression_Steel =
(1 + ((100* Area_of_Steel_In_Table /
(Beam_Width * Beam_Depth)) / (3 + 100 *
Area_of_Steel_In_table / (Beam_Width * Beam_Depth))))
End If
End If
If Modification_Factor_For_Compression_Steel > 1.5
Do Modification_Factor_For_Compression_Steel = 1.5
End If
Actual_Depth_Required = [Length_Of_Beam /
(Modification_factor_For_Compression_Steel *
Span_Effective_Depth_Ratio)]
If Actual_Depth_Required ≤ Beam_Depth
Do msg: Deflection criteria is satisfied
Else Do msg: Deflection criteria not satisfied
End If
End

```

## Environment description

Our experimental process for this paper was to develop a complete visual interface between a reinforced concrete design system (RCD) and our target user base (RCD analysts, investigators, designers, students and enthusiast). The RCD we have selected is the SSRCBS. This RCD is a highly configurable collaborative system, arranged both hierarchically and in a distributed way, permitting data to be gathered from a well laid out struc-

ture. This makes it particularly appropriate for use in investigating potential danger before final decision is taken. The failure may be due to bending moment, deflection or shear failure. The designs also address the issue of economy since our aim is to design a safe and economic structure. SSRCBS' design allows filtering of data sharing at any level (between input interface and output interface) and it is thus useful for adjusting the input-data-gathering activities with regard to the visualization in output domain.

## Prototyping SSRCBS

According to Waman (2005), prototyping is a proving tool to test the design of a system. A prototype for SSRCBS is shown in Figure 3. It enables us to fully understand and to gather insight into the SSRCBS system problems. It also give us as the designer a feel for the complexity of the system design comprising classes, objects and related interface.

Our prototype also helps in identifying use cases classes using Unified Modified Language (UML) approach, (Whitten et al., 2004) use case is an analysis tool for finding and identifying business events and responses for the purpose of completing a single business task as shown in Figure 4. In building the prototype a cross section of user representation from all user groups are considered to ensure that requirements across the board are considered and included as object in the UML.

## The RCD-SSRCBS Tasks

In order to design tools to support the tasks related to SSRCBS, it is imperative to understand how the work is accomplished. We followed the three phase-processes of monitoring, analysis and response.

The first phase is the monitoring of loads on the proposed beam structure using VisRCD Beam interface in Figure 5. Text box, combo box, slider control were generously used to enter beam parameters. For the analysts we interviewed, they consider this process an easy and interesting task of interacting with input parameters. They were enthusiastic with how Right-Angled Triangular Loading is mirrored using one stone to kill two birds. It should be noted that many analysts do require more types of loading other than what is proposed thus limiting their choice. This can be accommodated at a later time as the need arise.

The transition from monitoring to analysis is triggered by a button labelled Finalize, the allocated loads is automatically visible in the text editor interface in Figure 6, where analysis will be performed through the menu items. The file processing menu contains write text to file sub menu which when triggered save the loads into a file

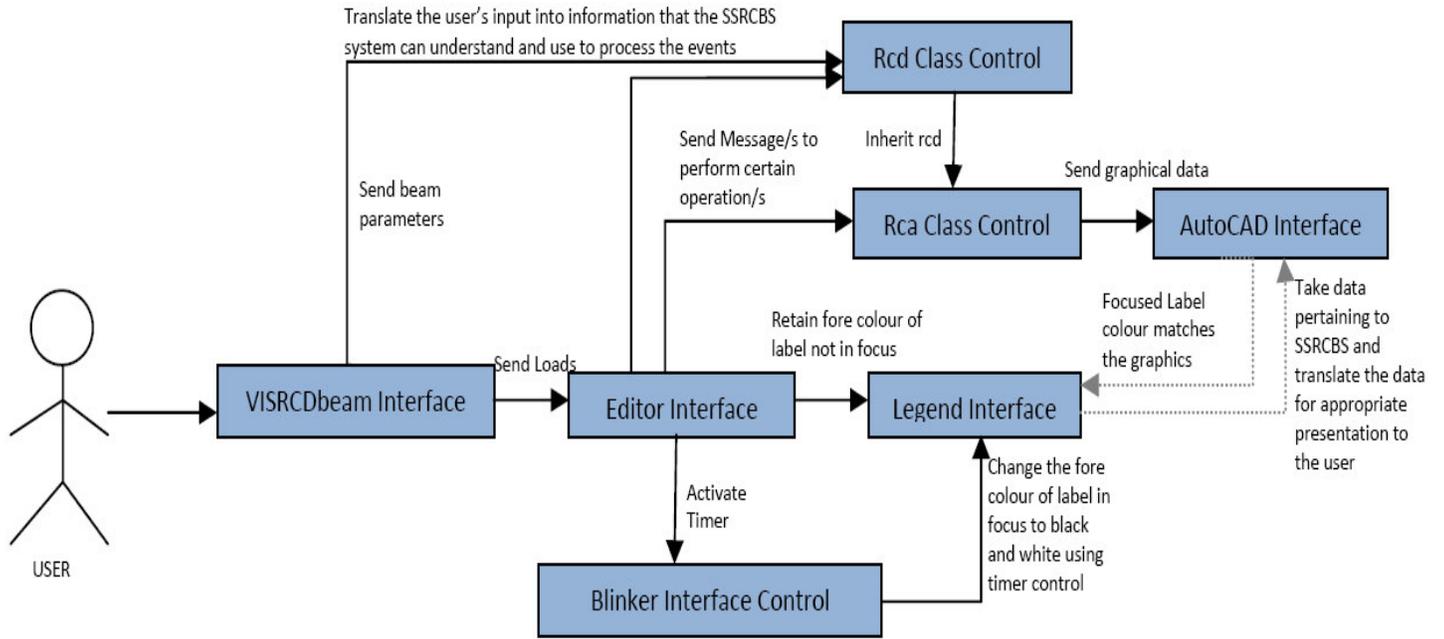


Figure 3. SSRCBS Objective framework architecture.

to be later used for analysis.

The process menu (Figure 7) contains analysis sub menu which when triggered activate and draw shear force and bending moment diagram into the AutoCAD interface environment.

Our participants recommended the use of progress bar control during the process and detailing development, their advice was well received and implemented as revealed in Figure 8.

The colour of the Bending Moment and Shear Force diagram exposed in AutoCAD Interface is an indication of the design status/condition which is indicated by colour coding in another window environment called Legend Interface as reflected in Figure 9.

The colour that blinks with the message written on it has the same match with the colour with which the diagrams are drawn in the AutoCAD environment. The Legend Interface also has a monitor that exposes certain output values that help the analyst to make a quick decision as at when necessary. The zoom tool is used to reduce or enlarge the graphics. When the analyst is not satisfied with the output, he moves the existing drawing away from its present location, change one or two input parameters, triggered finalize button and process once again until he/she is satisfied.

If the analyst is satisfied with the result of the analysis, he/she go back to the process menu and trigger the detailing sub menu. The beam detail including dimensioning and labelling is automatically visible below the initial diagrams as publicized in Figure 10.

Because it takes about thirty-six seconds for the software tool to load all the interfaces completely, we

arrest our user’s attention and focus with splash screen which includes progress bar.

We placed much emphasis on the tool and the desired outcomes the tool need to achieve among the users. We took into cognisance that today’s user wants a tool and not another hobby. We used “User-Centered Design” approach to achieve this. We adopt empirical measurement for the SSRCBS tool usage and finally we iterate our design whereby our tool is designed, modified and tested repeatedly. We trust that a usable tool must be useful, effective, learnable and likeable.

**RESULTS**

Table 2 shows the participants that perform SSRCBS tasks successfully with regard to the time benchmark, including those who required assistance during the task. The table also shows combined summary of tasks, task timing and the standard error for each task. For this particular work, a score was considered correct only if it is performed within the benchmark as indicated in the table. The benchmark to perform all task is 6.5 min, all participants were able to achieve this.

We test if we have obtained statistically significant results using student’s t-test distribution for each of the two groups; student t test distribution has a distribution that is mound-shaped and symmetrical (Brase, 1995).

$$t = (x_{bar} - \mu) / (s/\sqrt{n})$$

Where;  $x_{bar}$  = sample mean,  $n$  = sample size,  $s$  = sample standard deviation

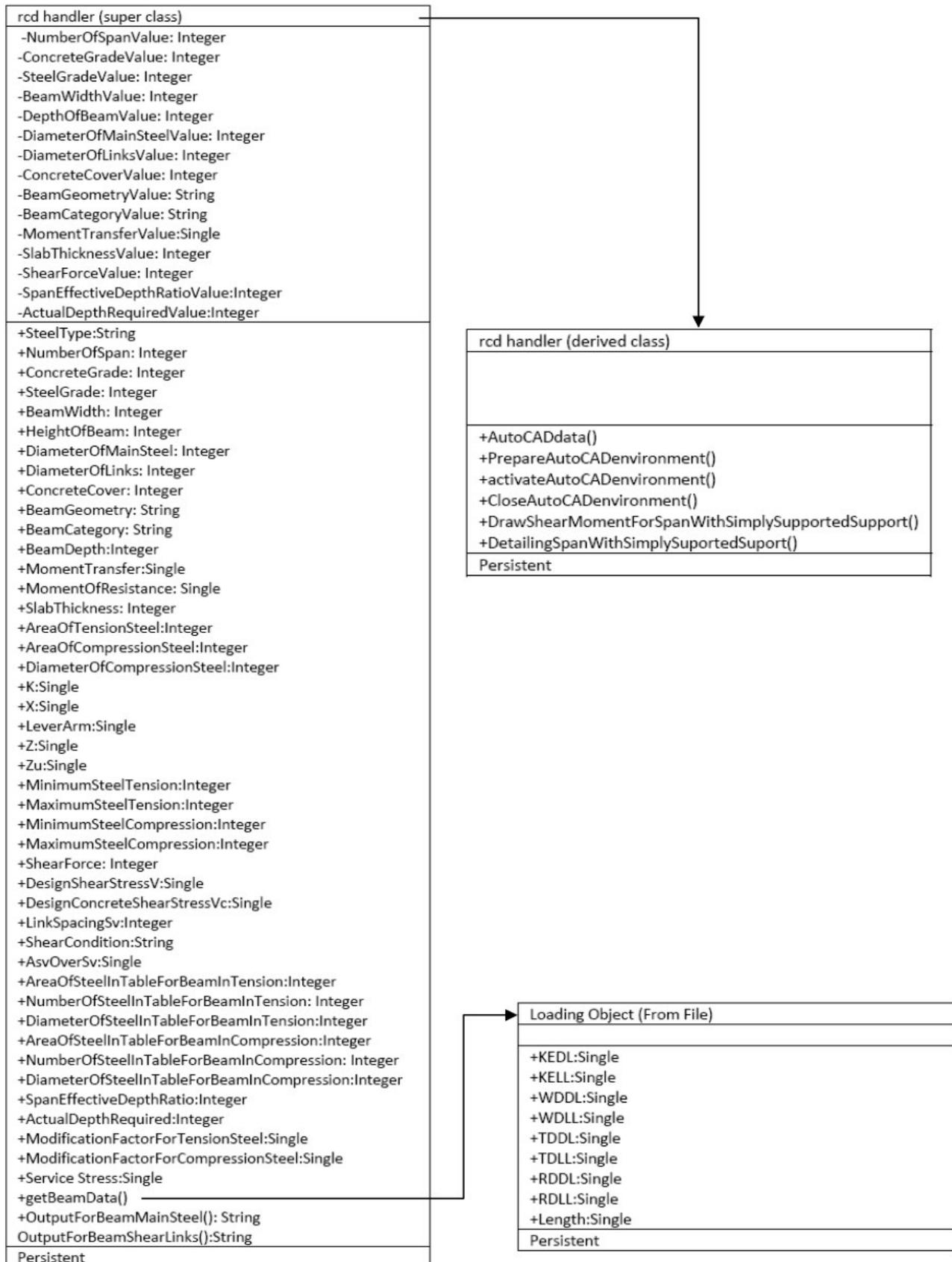


Figure 4. Definition of super class, derived class and load object using UML diagram.

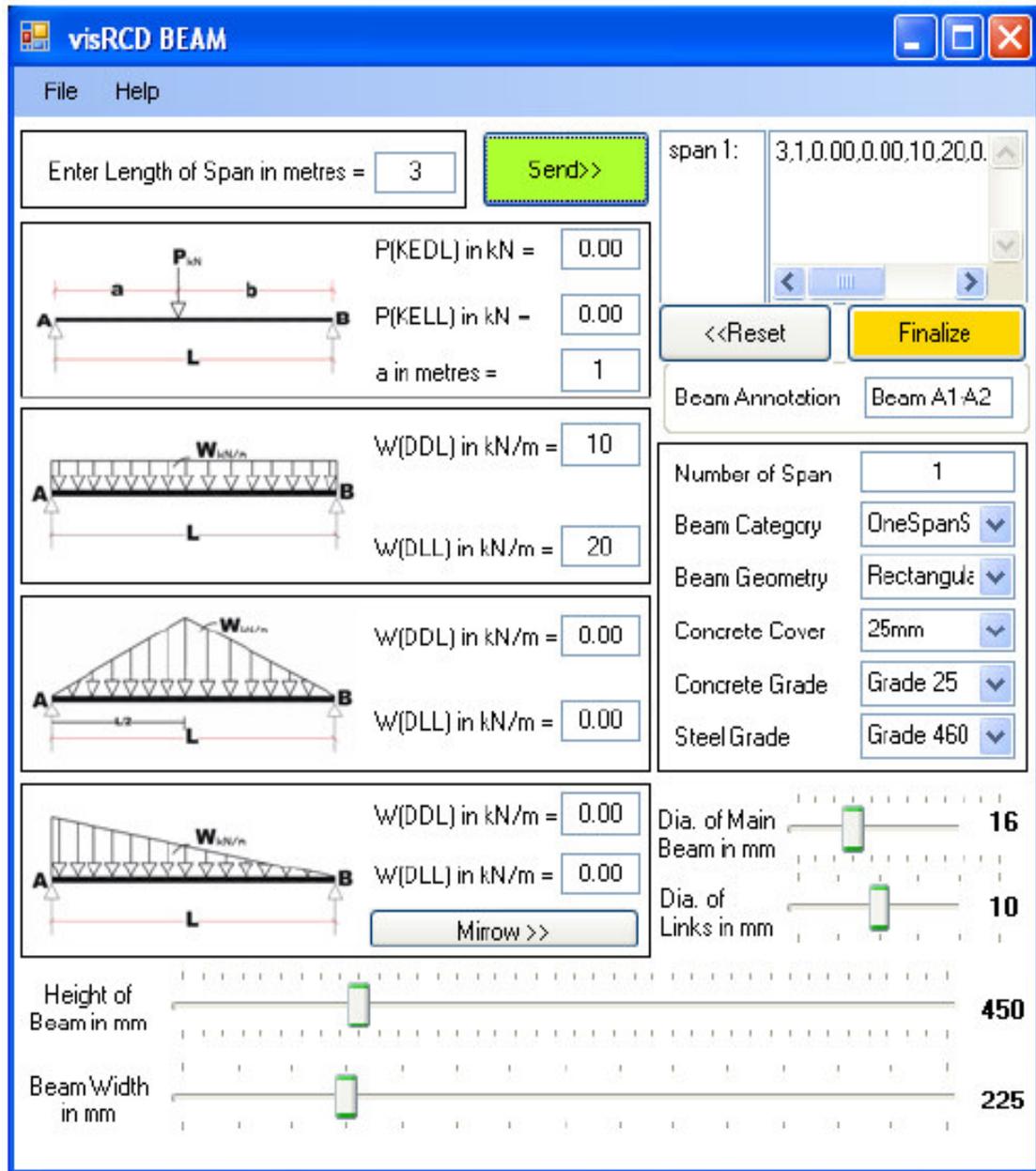


Figure 5. SSRCBS interface.

Degree of freedom, d.f. =  $n-1$

For our RCD analysts, using a one-tailed t test we look in the column headed  $\alpha' = 0.01$  and the row headed by d.f. =  $10 - 1 = 9$ . The critical value is  $t_0 = -2.821$ .

We now convert the sample test statistics  $x_{\text{bar}}$  to a t value

$$\begin{aligned} \mu &= 6.5, n = 10 \text{ and } s = 0.48 \\ t &= (4.86 - 6.5) / (0.48 / \sqrt{10}) \\ &= -10.25 \end{aligned}$$

Since the sample test statistic falls in the critical region, we reject  $H_0$ . It seems that the Mean Time to complete the

task do not exceed 6.5 min for the RCD analysts. The hypothesis was also positive for the computer enthusiast.

From the survey conducted we are able to discern that it will take the RCD analysts an average of one hour to achieve the task manually while not less than fifteen minutes will be required with commercial based PC software. None of the computer enthusiast has ever carried out SSRCBS either manually or with PC based software. A criterion for assessing whether a system is easy to learn is to apply the "ten-minute rule" (Nelson, 1980). It proposes that novice users should be able to learn how to use a system in under 10 min. If not the

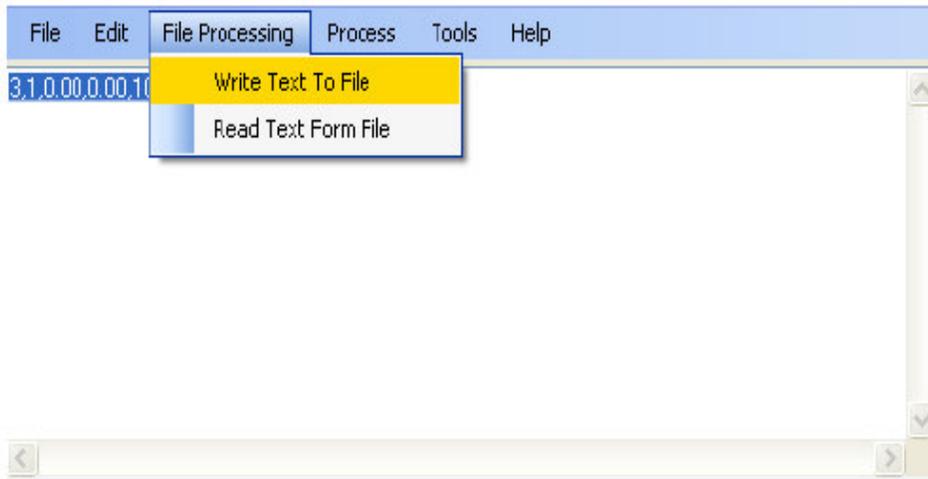


Figure 6. SSRCBS Text editor.

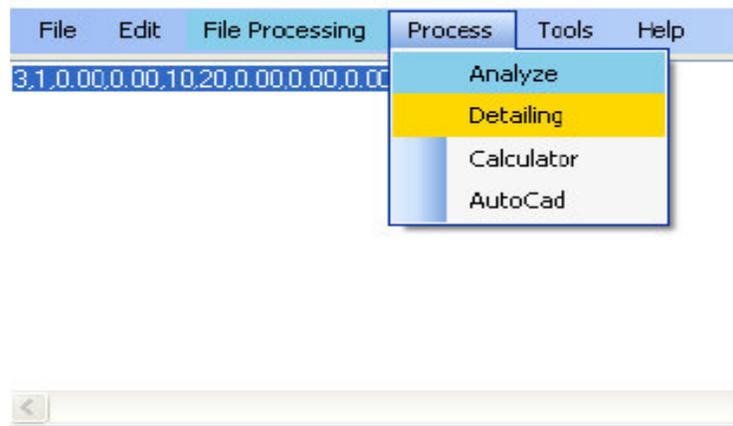


Figure 7. Process menu showing other sub menus.



Figure 8. Progress bar with message alert.

system fails, our hypothesis testing reveal that RCD analyst will perform task and achieve acceptable results

in less than 6½ min. Malik (2006) defined an exception as an occurrence of an undesirable situation that can be

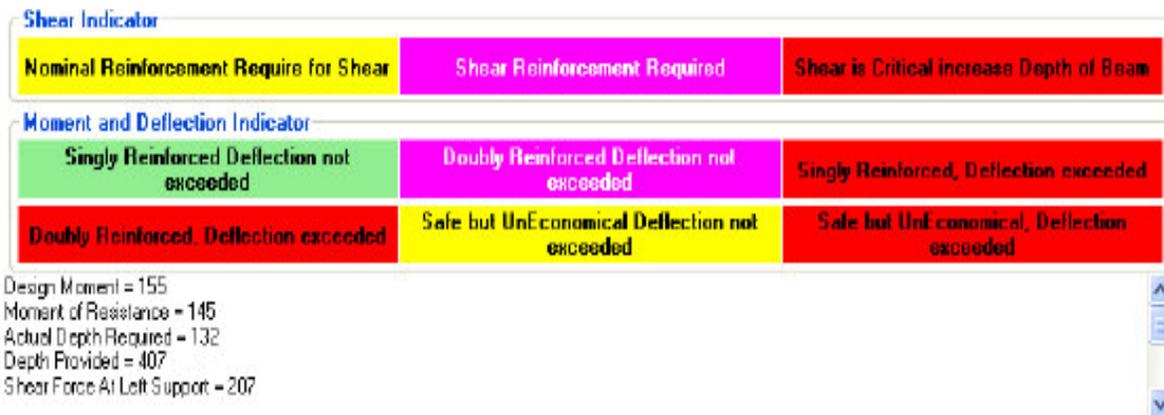


Figure 9. Legend interface for colour coding.

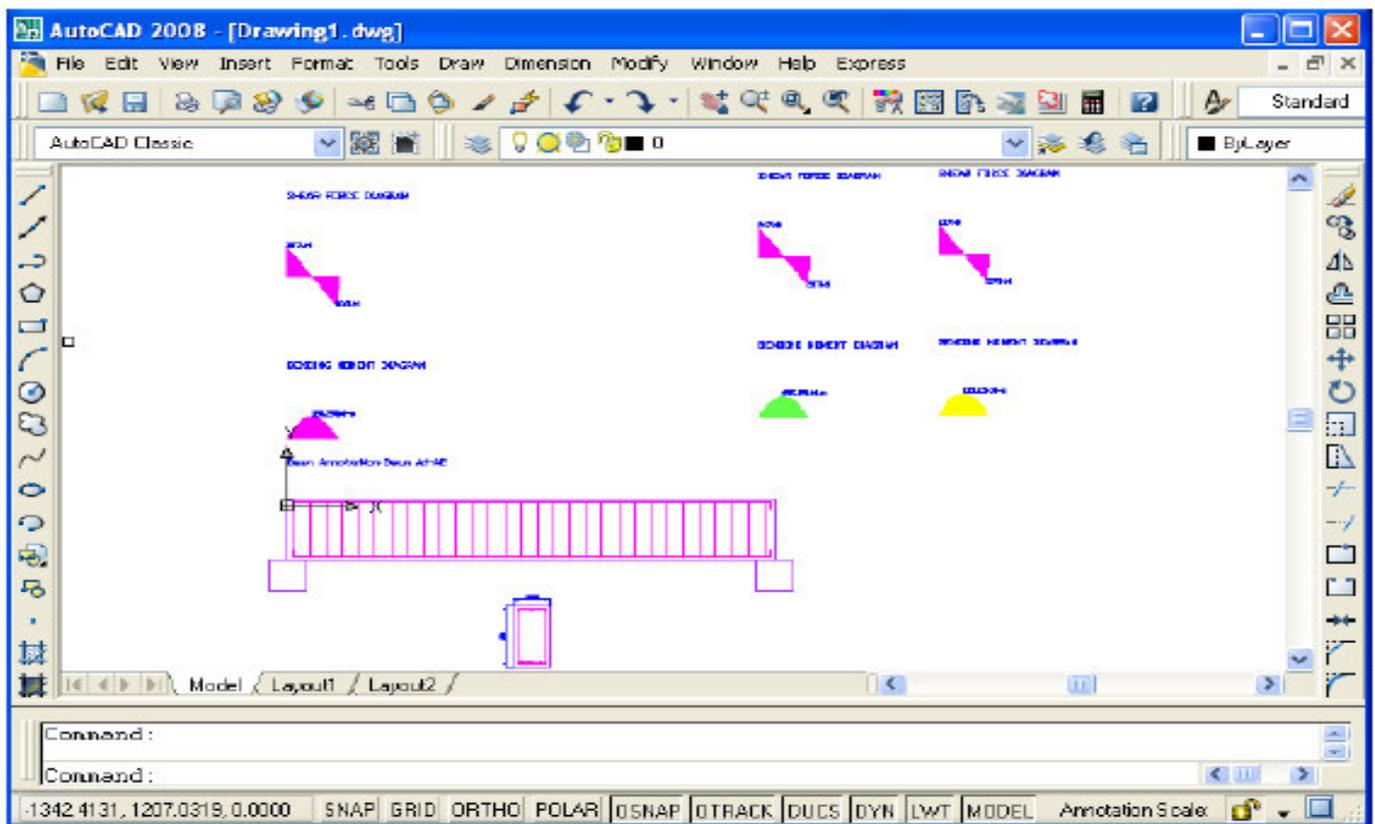


Figure 10. AutoCAD Interface as visualization environment.

detected during program execution. We tried to handle all known exceptions; those that are not visible were caught under general errors with error message alert. Users were tailored on the next action to be taken by colour coding the button or menu to be clicked in golden colour (relational mapping) and once the button or menu loses focus it goes back to its original colour. Occasional interruption of processing by the users who unknowingly

perform another task when they should wait for the current task to complete (the output of the current task serves as the input of the next task) was resolved by providing a form with progress bar control that animate the progress of the processing task with an alert message telling the user to wait for the current processing to be completed. This arrests the user's attention and keep them focused and occupied. We tried not to

**Table 2.** Task versus elapse time for participants.

Participants	Tasks	Benchmark for the task	Percentage of participants performing correctly (within benchmark) %	Mean time to complete(min)	Standard deviation (min)
RCD Analysis	Set-up SSRCBS software	1.0	100	0.6	0
	Load SSRCBS software	1.0	100	0.98	0
	Process Input	3.0	100	2.28	0.29
	Analyze beam( First attempt)	0.5	100	0.18	0
	Detail beam	1.0	100	0.81	0.3
	Total elapse time to perform all task	6.5	100	4.86	0.48
Computer enthusiast	Set up SSRCBS software	1.0	10	1.6	0
	Load SSRCBS	1.0	100	0.98	0
	Process input	3.0	100	3.03	0.28
	Analyze beam(first attempt)	0.5	100	0.3	0.1
	Detail beam	1.0	100	0.32	0
	Total elapse time to perform all task	6.5	100	5.23	0.24

overrate the knowledge level of the users by providing help as part of the tool; this will assist the users with certain terminologies and methodologies in performing various tasks. The analysis led to the development of a process model for Simply Supported Reinforced Concrete Beam Structure work and related visualization needs. The participants are enthusiastic with the ability of the tool to allow for continuous allocation and revalidation of inputs with the need for focused attention.

**SAMPLE CODE**

**‘Sample program: To get beam loads and write values to a file for further processing**

```
Public Sub get Beam Data()
    Using MyReader As New _
        Microsoft.VisualBasic.FileIO.TextFileParser
        ("C:\mspb.txt")
        MyReader.TextFieldType = FileIO.FieldType.Delimited
        MyReader.SetDelimiters(",")
        Dim currentRow As String()
        While Not MyReader.EndOfData
            Try
                currentRow = MyReader.ReadFields()
                Dim currentField As Single
                For Each currentField In currentRow
                    N = N + 1
                    CF(N) = currentField
                Next
                kk = kk + 1
                Dim L As Single = CF(N - 9) : _ 'Length or
                Span of Beam
```

```
Dim a As Single = CF(N - 8) 'Distance of Knife
load from left support
Dim KEDL As Single = CF(N - 7) : _ 'Knife
Edge Dead Load
Dim KELL As Single = CF(N - 6) 'Knife Edge Life
Load
Dim DDLL As Single = CF(N - 5) : _
'Distributed Dead Load Linear
Dim DLLL As Single = CF(N - 4) 'Distributed Live
Load Linear
Dim DDLT As Single = CF(N - 3) : _
'Distributed Dead Load Triangular
Dim DLLT As Single = CF(N - 2) 'Distributed Live
Load Triangular
Dim DDLR As Single = CF(N - 1) : _
'Distributed Dead Load RightAngledT
Dim DLLR As Single = CF(N) 'Distributed Live
Load RighthAngledT
Dim pL As Single = (1.4 * KEDL) + (1.6 *
KELL) 'ultimate load for knife load
Dim IL As Single = (1.4 * DDLL) + (1.6 *
DLLL) 'ultimate load for linear load
Dim tL As Single = (1.4 * DDLT) + (1.6 *
DLLT) 'ultimate load for Triang load
Dim rL As Single = (1.4 * DDLR) + (1.6 *
DLLR) 'ultimate load for RightT load
L = L * 100
a = a * 100
Length(kk) = L : aLeft(kk) = a : aRight(kk) = L
- a
P(kk) = pL : W(kk) = IL : T(kk) = tL : R(kk) =
rL
Catch ex As _
Microsoft.VisualBasic.FileIO.MalformedLineException
```

```

        MsgBox("Line " & ex.Message & _
            "is not valid and will be skipped.")
    End Try
End While
End Using
Dim x As Integer
For x = 1 To kk
    Length(kk) = Math.Round(Length(kk), 2)
    aLeft(kk) = Math.Round(aLeft(kk), 2)
    aRight(kk) = Math.Round(aRight(kk), 2)
    P(kk) = Math.Round(P(kk), 2)
    W(kk) = Math.Round(W(kk), 2)
    T(kk) = Math.Round(T(kk), 2)
    R(kk) = Math.Round(R(kk), 2)
Next
End Sub

```

## Conclusion

This paper is geared towards the analysis and design of a Simply Supported Reinforced Concrete Beam Structures through the data collected from the user and visualization techniques being developed specifically for this purpose. We feel this research will greatly improve the ability for our user base to identify failure due to bending moment, deflection, shear and use their intuition to determine if the structure is economically sound and safe. Many RCD analysts and designers use commercial RCD software that limit their contributions to the design process thus making their perception not count. The capabilities we are developing are sorely needed and will provide great benefit to the user by making their observations and judgement count. Our testing was conducted with care and precision in the tool development cycle, and as part of an overall user-centered design approach which is an almost infallible indicator of potential problems and the means to resolve them. We have been able to minimize the risk considerably of releasing an unstable or unlearnable product. We are of the opinion that it is better to test than not to test. We believe that our SSRCBS tool has been made to fit the users rather than making users to fit our tool, we have also enhanced AutoCAD environment to identify potential failure in a Beam by observing the colour of graphical display in correlation to the activities taking place in the legend interface.

## FUTURE WORK

Since our environment will be used for reinforced concrete beam structural design, we must provide for other types of beams that is, cantilever beam, propped beam, continuous beam of varying end conditions etc. The interface work well with AutoCAD 2008, using the software for other version of AutoCAD without tampering with the source code is an issue to be addressed. Addi-

tional issues that we must resolve, for example; How can we visually represent a moving load (influence line) on a beam, how can we visually accommodate more types of loadings without occluding or hiding important details. Is the current metaphor for visual representation appropriate for our user base or should we choose an alternative visual.

## Recommendation

In the course of administering the questionnaire, it was observed that human nature, attitude and perception of the respondents are important parameters in the success of this research work. In line with our findings therefore, it is essential that all science based disciplines and professions in developing countries should have basic knowledge and understanding of psychology most especially in the post-secondary school curriculum so that people's behaviours, perceptions, designs and operations can achieve the desired success and result.

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