SESOC Software – Seismic Design Tools

G. Bird

SESOC Management Committee, & Beca, Auckland

A. McPherson

SESOC Software Support, & Maxx Information Systems, Wellington

ABSTRACT

SESOC has accumulated a number of structural software design programs, over time, which we actively maintain/enhance, also on occasion developing a new tool for the benefit of our members – and the NZ design fraternity.

This paper covers two recent developments/enhancements, namely :

- "Gen-Wall", a new program developed specifically for the design of reinforced concrete (RC) shear walls to NZS 3101 – and particularly the associated confinement & ductility provisions
- "MemDes", a comprehensive (segment) steel design program, being enhanced to provide additional design capabilities eg for seismic assessment etc

This paper briefly introduces the software, with particular focus on the recent enhancements, - as well as some of the issues in implementation, and nuances to be aware of in use.

1 INTRODUCTION

1.1 Software Origins, Philosophy, & Disclaimer

It was by happenstance, back in the 1990s, that SESOC became involved in software, as a result of the considerable enthusiasm of one of our early members, Esli Forrest. He initially developed the Soils program, later followed by the BeamDes program. Further software has been added over the years, some being 'handed on' to SESOC, and some being intentionally developed to fill a particular need. Further detail is provided in the SESOC Software Overview [1] paper presented by the present author to the 2017 SESOC Conference.

For clarity, the reader should be aware that SESOC is not in the business of providing software per se, but rather it is in the business of providing value to its members - of which software is a part. Clearly, as informed by the software usage statistics, our members are valuing the software aspect as a significant part of the SESOC membership package & benefits.

Further information is provided in [2] regarding provision of software to individual members only (cf companies), software licensing & support, avoidance of competition with commercial software, etc.

Users are specifically directed to the disclaimer on each program, and are expected to use the software appropriately. In particular, the software is not intended for design circumstances beyond the users' competency, or where they would not be able to independently undertake hand calcs for verification or other purposes.

2 GEN-WALL

2.1 Background

Although software is generally available which carries out 'broad' shear wall design, e.g. flexure and axial, there is no commercially available software which addresses the specific design provisions of the NZ Concrete Standard, NZS 3101. Further, anecdotally, there are few, if any, consultancies which have robust in-house software to address this.

As RC shear walls are an integral and key part of a large number of New Zealand buildings, it is important that these are designed and detailed correctly.

Further, due to the multitude and complexity of the NZS 3101 structural wall shear, confinement, and ductility provisions, it is postulated that properly implemented software is the only option – hand calculations being prohibitively time consuming, and hence commercially untenable, for all but the simplest shear walls.

For these reasons – and the benefit of our members, SESOC embarked on the development of this software.

2.2 Scope

In broad terms, the program comprises :

- A standalone, purpose built interactive design tool
- Reinforcing design and detailing capabilities, including
  - Flexure, shear, and confinement, to NZS 3101
  - Singly and doubly reinforced
  - Sectional design (check) program basis,
- Geometry-wise, the following doubly symmetric section shapes:
  - Rectangular
  - Rectangular with enlarged boundary element at each end
  - Rectangular with end flanges
- Ductility-wise, nominally ductile, limited ductile, & fully ductile

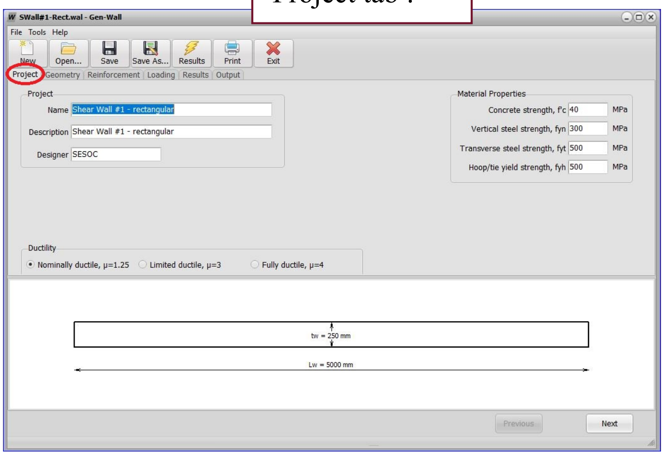
2.3 Implementation

Gen-Wall is presented in a tabular interface format, similar to MemDes and the more recent MemDes+.

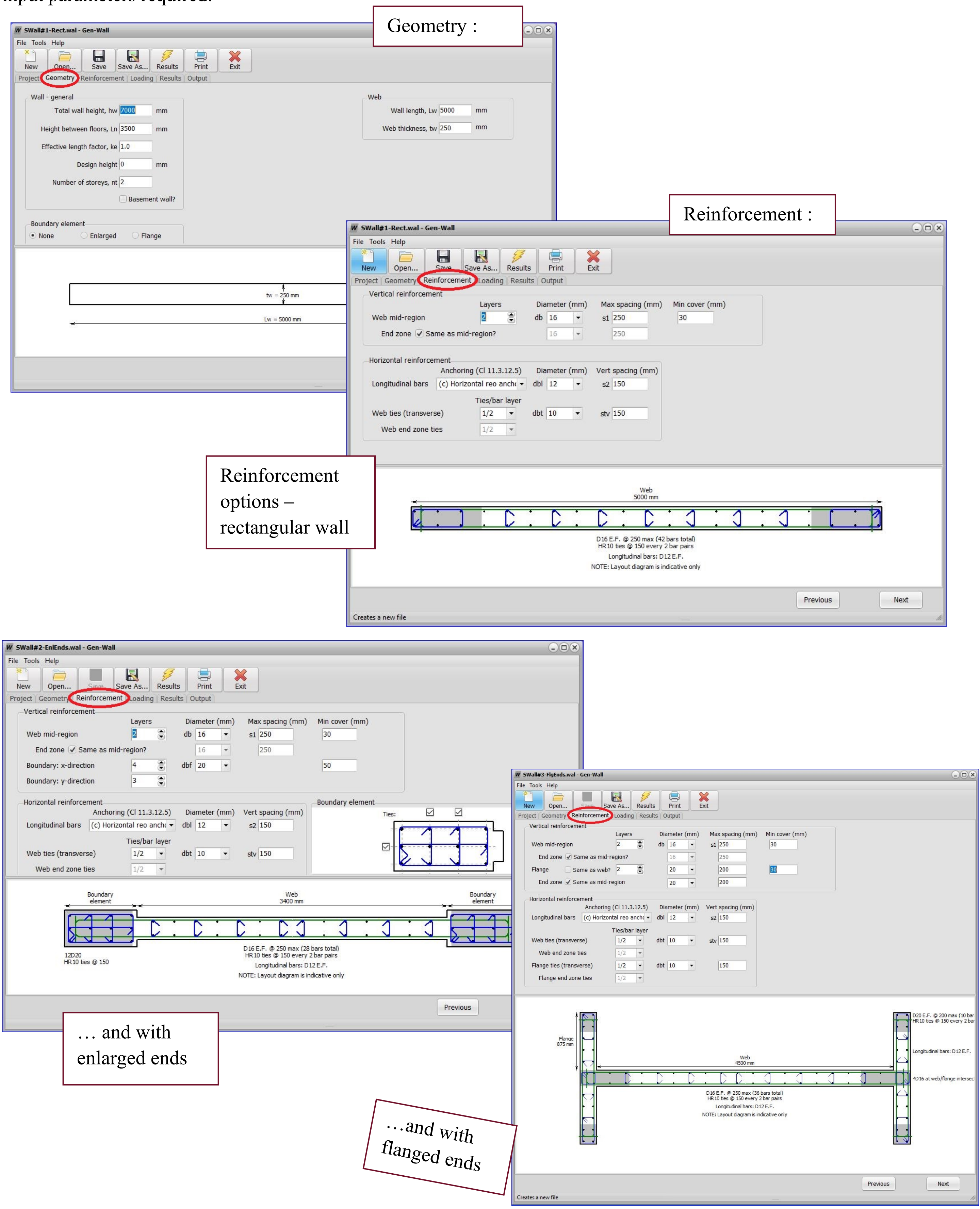
Significant effort has been expended to make the program as simple and intuitive as possible. Further, graphical representation provides immediate visual feedback on the designers' input, where possible.

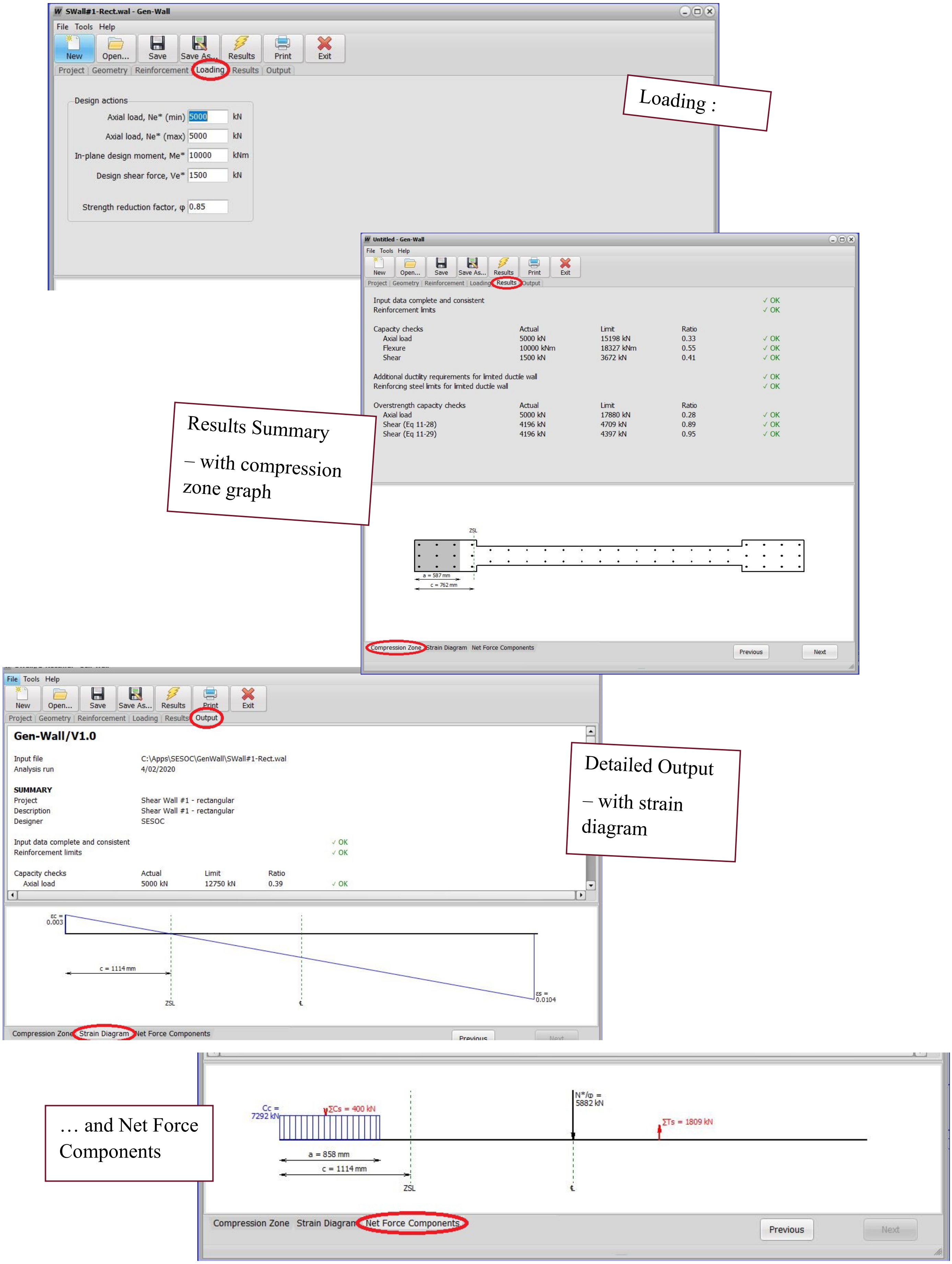
Depending on the chosen wall type and/or design options, unnecessary input fields are hidden, in order to focus the user's attention on the necessary data content.

Project tab :



The following series of screenshots demonstrate the look and feel of the interface, program structure, and input parameters required:




Loading :
Results Summary
– with compression zone graph
Detailed Output
– with strain diagram
… and Net Force Components
SWall#1-Rect.wal - Gen-Wall
File Tools Help
New Open... Save Save As... Results Print Exit
Project Geometry Reinforcement Loading Results Output
Design actions
Axial load, Ne* (min) 5000 kN
Axial load, Ne* (max) 5000 kN
In-plane design moment, Me* 10000 kNm
Design shear force, Ve* 1500 kN
Strength reduction factor, φ 0.85
Untitled - Gen-Wall
Input data complete and consistent ✓ OK
Reinforcement limits ✓ OK
Capacity checks Actual Limit Ratio
Axial load 5000 kN 15198 kN 0.33 ✓ OK
Flexure 10000 kNm 18327 kNm 0.55 ✓ OK
Shear 1500 kN 3672 kN 0.41 ✓ OK
Additional ductility requirements for limited ductile wall ✓ OK
Reinforcing steel limits for limited ductile wall ✓ OK
Overstrength capacity checks Actual Limit Ratio
Axial load 5000 kN 17880 kN 0.28 ✓ OK
Shear (Eq 11-28) 4196 kN 4709 kN 0.89 ✓ OK
Shear (Eq 11-29) 4196 kN 4397 kN 0.95 ✓ OK
ZSL
a = 587 mm
c = 762 mm
Compression Zone Strain Diagram Net Force Components
Previous Next
Gen-Wall/V1.0
Input file C:\Apps\SESOC\GenWall\SWall#1-Rect.wal
Analysis run 4/02/2020
SUMMARY
Project Shear Wall #1 - rectangular
Description Shear Wall #1 - rectangular
Designer SESOC
Input data complete and consistent ✓ OK
Reinforcement limits ✓ OK
Capacity checks Actual Limit Ratio
Axial load 5000 kN 12750 kN 0.39 ✓ OK
εc = 0.003
c = 1114 mm
ZSL
εs = 0.0104
Cc = 7292 kN
ΣCs = 400 kN
N*/φ = 5882 kN
ΣTs = 1809 kN
a = 858 mm
c = 1114 mm
ZSL

2.4 Aspects of Particular Note

2.4.1 Conceptual Layout versus Detailing

Gen-Wall attempts to show, as accurately as possible, the wall geometry and conceptual layout of reinforcing, for the purpose of accurate implementation of code checks.

It is not, however, a detailing program – the finer details of bar laps, end anchorage and termination etc. are of necessity left to the designer. Thus, there may be, at times, unusual aspects in terms of the graphical presentation, e.g. 90° bend terminations protruding from the wall.

The designer is expected to attend to the minutiae of exact bar placement, bend radii, etc.

2.4.2 Vertical Reinforcement Layout

Gen-Wall automatically lays out vertical reo along a web or flange and within an enlarged boundary element based on a minimal number of parameters specified by the user. This gives a fast and convenient way to quickly input and update layout during design, but does not give full control of exact bar locations to the user for a non-standard layout, e.g. irregular bar spacings.

Separate input is provided for end-zone and mid-regions. To minimise input requirements, Gen-Wall has the option to set end-zone reinforcement data to be the same as those for the mid-region, and/or set flange reinforcement data to be the same as those for web.

2.4.3 Hoops/Ties/Stirrups

Again, Gen-Wall automatically generates ties based on user-specified parameters. Arrangement of ties along the web or flange is primarily determined by the specified ties per pair of vertical bars (1/1 to 1/4).

2.4.4 Horizontals – Layout and Termination

The user has a choice of three different horizontal bar end terminations:

- Horizonal bar laps
- Corner bars anchored with hooks and local ties
- Horizontal reo anchored at the ends with 90° hooks and surrounding cage

These are presented irrespective of the wall type, though some are more suitable for different wall type(s) than others.

2.4.5 Confinement to Ends

As confinement to the wall ends is required in virtually all situations, and horizontals bar diameter plus deformations plus higher yield steel results in a (typically) larger radius bend, closed hoops are automatically provided to the wall end.

Geometry and sizing are ascertained according to the relevant 'Web ties' information.

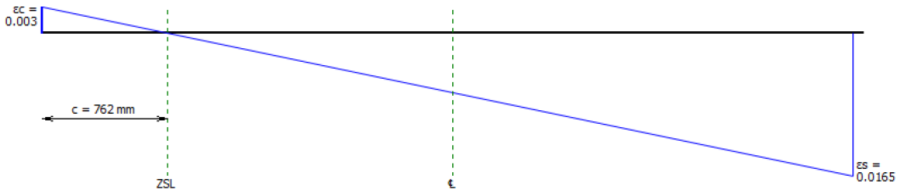
2.4.6 Plane Strain Assumption

The program is a sectional analysis tool, based upon the 'plane strain' assumption, as per NZS 3101. It is the responsibility of the designer to ensure compliance with this assumption, especially around transition areas, where this assumption may not be valid, and to design/detail accordingly, e.g. shear wall founded on end poles.

2.4.7 Zero Strain Line (ZSL)

Gen-Wall uses the term zero strain line (ZSL), as a more correct description of what is commonly called the neutral axis (N.A.). Strictly, the location of the neutral axis is a function of the cross-section only, not taking into account any applied axial loads. Assuming "plane sections remain plane" under applied axial and moment loads, the strain graph is a straight line, and the ZSL is the location where the value of the strain changes sign (i.e. is zero).

A sample diagram is shown :

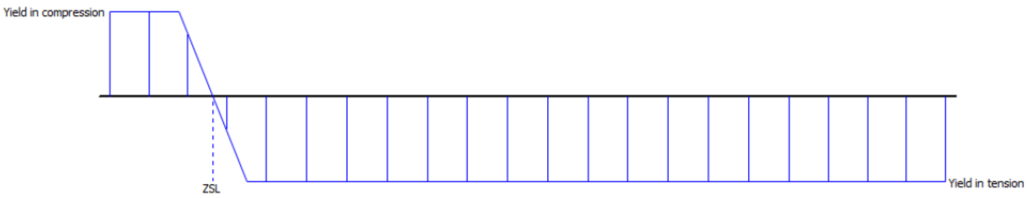


2.4.8 Overstrength Calculations

While 'elastic' analysis – and the 'plane strain' assumption form the basis of NZS 3101 – and core of the program, such an approach is not valid for overstrength calculation. For example, the wall may have undergone any number of previous cycles, of any arbitrary loading/displacement sequence. And so, for a particular cycle, the 'commencing' strain, and hence yield stress, is unknown. In terms of an analytical model, steel is assumed to be fully yield, in either compression or tension, on each side of the 'zero strain line' (ZSL). This is in accordance with industry practice – and code expectations.

However, from a computational perspective, such an approach is problematic, and so has been 'softened' to a small region of 'linearity' around the ZSL, in order to provide a more 'transitional' apportionment of steel tension and compression components versus the abrupt changes otherwise.

To elaborate, and for example, the change of 1 or 2mm in position of the ZSL can change any number of bars in that <u>immediate</u> vicinity from full tensile yield to full compressive yield, or vice versa. This is particularly problematic when the ZSL perchance aligns with multiple bars in a flange or enlarged end. This seems unreasonable – and difficult to resolve in terms of equilibrium, and so the introduction of the 'softened' approach in the immediate vicinity has been taken, with minimal effects on the overall flexural capacity.



2.4.9 Output Results

As indicated on the screenshots above, two levels of results are provided:

- Summary results
- Detailed output

Summary results present the key design stages as a series of single-line descriptions with a stage results (OK, FAIL, or CHECK). Capacity values and limits are provided for axial load, flexure, and shear.

Detailed output is displayed on-screen (and printout) with detailed equations and cross-references to the relevant NZS 3101 clause and equation numbers. This allows the designer to manually verify Gen-Wall's approach and specific implementation of NZS 3101.

2.4.10 Singly Reinforced Rectangular Wall – Ductility Limitations

The following extract, snipped directly from the user documentation, summarises the key conclusion on this aspect, in particular the prevention of use of a singly reinforced, rectangular wall (ie no end boundary elements, whether flange or end 'column') subject to proposed ductility expectations.

> ***7.1 Warning about singly-reinforced walls***
>
> The designer must use the singly-reinforced provisions of NZS 3101 with care. Gen-Wall does not consider actions causing bending about the minor axis, or carry out stability calculations.
>
> **PLEASE NOTE that questions have been raised regarding the appropriateness of singly-reinforced walls subject to reverse cyclic loading and likely instability under load reversal. This is currently being debated at industry level, and the option to analyse these walls has been removed from Gen-Wall in the interim.**

To expand: as the reader will appreciate, under tensile action reinforced concrete displays a huge stress/strain variation between the concrete and steel components. Similarly, under ULS flexural loading/displacement, in the region of the extreme tensile fibre, the steel may be at many times the yield strain, with, in effect, disparate pieces of cracked concrete along the length of a particular piece of rebar.

However, under load reversal, and viewing from a cross-sectional perspective, we have a (single) piece of strained rebar, which must now yield in compression in order to form the necessary composite concrete/steel compressive stress block.

But what about the stability aspects ? - with the cracked concrete providing minimal lateral ie out-of-plane stability to the extremely slender piece of rebar ?

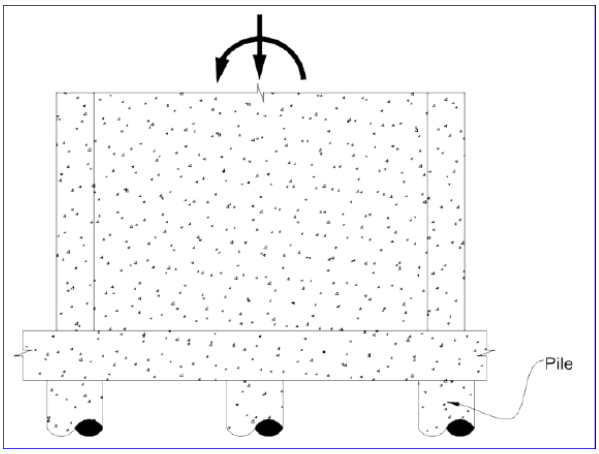
Clearly, such an element, or portion of the wall, is subject to high buckling tendencies, which is in all probability unlikely to perform satisfactorily, should the designer be expecting some degree of ductility.

Although not excluded by the code, this has been raised by industry leaders as a matter of concern, in particular by Dr Richard Fenwick. In the interim, SESOC has taken the position of disallowing ductile design of singly reinforced walls.

To be clear, this aspect ONLY applies to singly reinforced walls. As soon as we have a doubly reinforced wall, and/or enlarged end region or flange, irrespective of concrete cracking etc, we have moment stability by virtue of the multiple pieces of rebar able to form a moment couple.

2.4.11 Analysis Versus Design

It is incumbent on the designer to properly understand the physical reality of the wall under consideration, versus the analytical model, and versus the NZS3101 (and Gen-Wall) implementation.

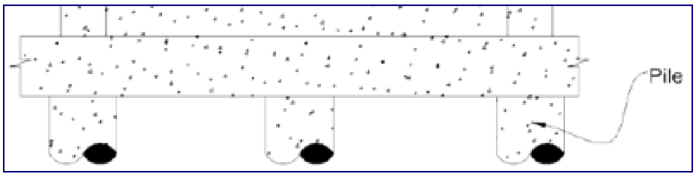


For example, in the adjacent graphic, the typical structural analysis will show zero axial load in the middle pile from the moment only loading. However, in terms of the real ULS assumed stress block wall behaviour, clearly this is incorrect, and in conflict with the linear strain profile basis of NZS3101 – resulting in non-linear stress/force components.

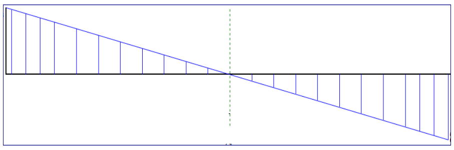
To present in another way, the typical analysis assumes a linear relationship between stress and strain. However, for reinforced concrete subject to tension or flexure, clearly this is not valid. Thus, while analytically the middle pile is at the centroid of the (supporting) elements, (and hence implied axial force is zero), from a design perspective the flexural response from the actions imposed on the (supported) RC member result in a neutral axis (NA, or ZSL) towards the compression side.

The following graphics attempt to demonstrate the difference in the analytical versus design stress/strain behaviours :

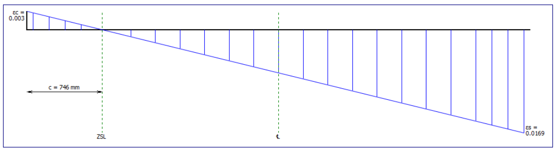
- Physical model



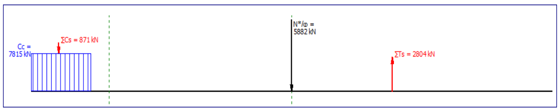
- Underlying linear stress/strain model



- Design model – strain profile



- Design model – stress/force components



In an additional, but related note, overstrength aspects must also be considered as part of the final design, and the proper and robust transfer of load through sectional variances or interfaces.

These are just two examples where the designer cannot blithely accept the output of a particular analysis or design software and 'simply' marry these together, but must understand the inherent mechanisms and load paths, and design & detail accordingly.

3 MEMDES

3.1 Introduction

Available to engineers for 20+ years, MemDes has arguably been a key design aid in the toolbox of many consultants throughout NZ. Based on, and incorporating a wide range of standard sections, however, this precluded the ability to extend to older or non-standard section sizes or grades.

This matter has now been addressed, with the addition of :

- Ability to take any standard library section, and modify any or all of its parameters
- Extended capability in terms of custom welded "I" sections

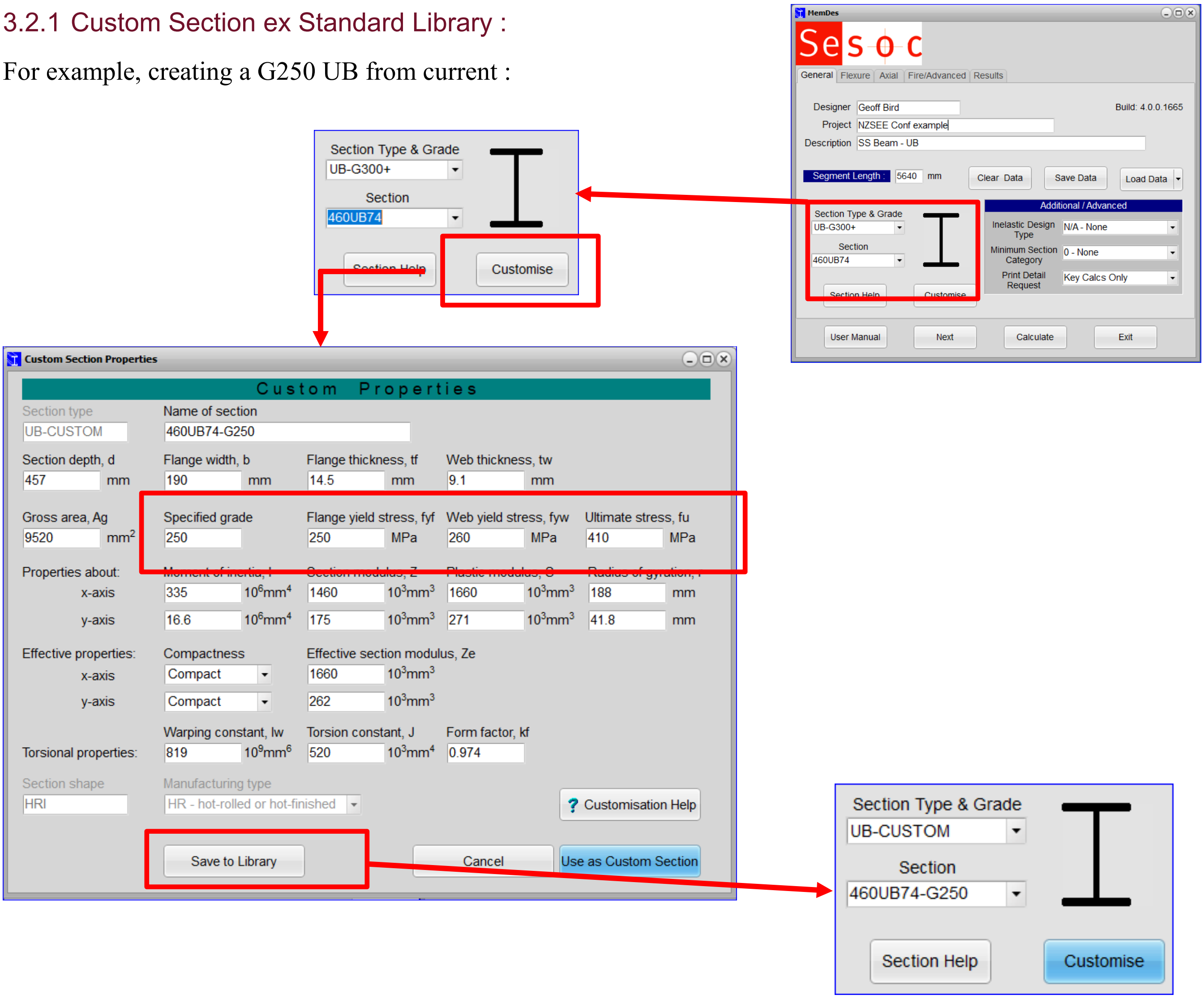
These enhancements allow the design of practically any section size, or grade, e.g. historical steel beams or columns as part of a seismic assessment, local or imported fabricated beams, etc.

3.2 New functionality screen-shots

The following screen snips demonstrate the broad implementation of the new functionality. Section properties are saved locally in to a 'Custom' library on the users computer.

3.2.1 Custom Section ex Standard Library :

For example, creating a G250 UB from current :

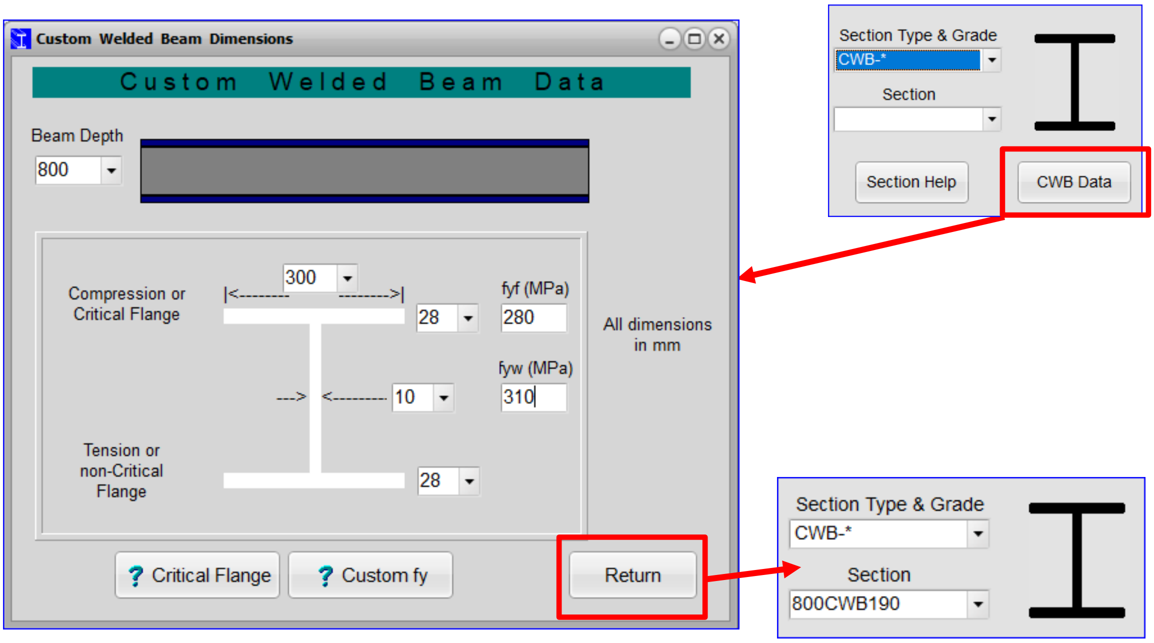


As the knowledgeable designer will be aware, some of the section design parameters are inter-related, e.g. steel grade & yield affects element slenderness ratios and potentially the effective section modulus, etc. It is thus incumbent on the designer, when using the CSLS capability, to ensure that all relevant provisions of NZS3404 are complied with.

3.2.2 Custom Welded Beam :

Custom welded beams were solely around the NZ Steel/Steltech product range and availability.

The new functionality allows for wider use of such fabricated members.



Notes:

1) The typical section properties are calculated internally, as per NZS 3404.
2) f_u is assumed to be as per the below :
   - Up to Grade 350 : $f_u = 1.28 * fy$
   - Above Grade 350 : $f_u = 1.11 * fy$

This minimises data entry, as well as simplifying internal data systems,

While f_u is expected to be used only rarely, if ever, the designer should be cognisant of this aspect.

4 CONCLUSION

This paper has provided a brief overview into the Gen-Wall RC shear wall design software, as well as some aspects for thought around use of the software, especially around practical implementation.

Gen-Wall is already proving to be a valuable tool in the NZ structural design environment, and has received good feedback to date.

MemDes has proved to be a useful and trusted design tool for two decades plus, across a broad range of consultancies. The new functionality will further expand and enhance its use.

Of necessity, this paper has only overviewed some of the aspects, of these software programs. Further detail is provided in the documentation associated with each.

5 REFERENCES

[1] SESOC Software Overview, 2017, Geoff Bird, SESOC Conference 2017 proceedings

[2] Shear Wall Design Tool - SESOC, 2021, Geoff Bird, NZSEE Conference 2020 proceedings