Enhancing collaboration between architects and structural engineers using preliminary design software

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ABSTRACT: For over twenty years RESIST software has been used by architectural students to design their project structures for wind and earthquake loads. The most recent version of RESIST, which has just been released for free download, has the potential to enhance the collaboration of architects and engineers at the crucial early stage of a design project.

The paper begins by discussing aspects of architect-engineer collaboration with an emphasis on the implications of architects' iterative design approaches. Then we describe RESIST and highlight the most recent improvements.

Given that RESIST is for preliminary design only, its features allow alternative lateral load-resisting designs to be very quickly completed and compared. This ability to generate alternative structural systems relatively effortlessly makes it a valuable tool in enhancing the iterative nature of architect-engineer collaboration.

1 INTRODUCTION

The timing of this paper coincides with discussion on the importance of architect-structural engineer collaboration and the free availability of the preliminary structural design software, RESIST (Charleson and Wood 2014). Concerns regarding inadequate collaboration have emerged following the damaging 2010 and 2011 Canterbury Earthquakes. In particular, the following two recommendations from the Canterbury Earthquakes Royal Commission (2012) highlight the need for early and more extensive collaboration:

> 163 A structural Chartered Professional Engineer should be engaged at the same time as the architect for the design of a complex building.
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> 185 The Institution of Professional Engineers New Zealand, the New Zealand Institute of Architects, and the New Zealand Registered Architects Board, supported by the Ministry of Business, Innovation and Employment, should work together to ensure greater collaboration and information sharing between architects and structural engineers.

In response to these recommendations a working group with representation from IPENZ, ACENZ, NZIA, NZRAB, MBIE, SESOC and NZSEE has prepared a draft practice note that is currently under review.

At the same time as architect-engineer collaboration is in the spotlight, the RESIST software, primarily developed for use in educational settings, has become freely available for engineers and architects to use in their design projects. RESIST is a tool with the potential to improve collaboration between the two disciplines in the context of specific building designs.

2 COLLABORATION

As a starting point for discussing aspects of collaboration between architects and structural engineers Tait (2012) provides a useful description of collaboration:

> In architectural terms, collaboration involves the design disciplines working together, often with the architect as lead designer – sharing knowledge, learning from each other, and building a project that reflects a consensus that this is the best solution. Collaboration among disciplines is an approach that acknowledges the process of design development: it depends on the analysis of the problems and an iterative feedback of design solutions and options to the entire team, so that collective decisions are made at each stage. This requires a methodology of presentation where the logic of design moves is explained – transparent and open for comment.

Collaboration is a challenge for both architects and engineers due to their different design foci and methods. For example, architects are responsible for *many* aspects of design as they seek to meet clients' expectations. They must satisfy both functional and aesthetic expectations, and as such may try to avoid the potential blandness of symmetry, regularity and orthogonality – sought-after structural characteristics! Architects frequently aspire to create a sense of lightness of building elements, whereas engineers' almost sole focus is upon 'grounding', or providing force paths from superstructure to foundations.

And what about the professions' differing design processes? They reflect the contrasting styles of professional education. Architects adopt an iterative process in an attempt to synthesise large numbers of design requirements. It's a bit like trying to complete a jigsaw puzzle with no single right or wrong outcome. Architects design and then rework their efforts, again and again, until all aspects are resolved. By contrast, engineers are far more narrowly-focused and prefer a linear design approach. Their goal is safe, economical and code-complying structures. A cultural shift is therefore required for engineers to adapt positively to architects' iterative design approaches. Structural engineers need to embrace the reality of collaborative and iterative design, contributing their expertise to the team's mix of ideas to keep the project moving forward, all the while acknowledging that a potential solution might shift and some amount of abortive discussion and effort is inevitable. At the same time architects need to move from an individualistic approach to design, to one that includes the input from a team of professionals. Sambhare (2012) elaborates:

> The key to successful interdisciplinary collaboration is in understanding that it is not a technology but rather a psychology. Collaboration is not a process that can be codified into a set system; it is more of an attitude that needs to be inculcated in the culture of a firm. It begins with every participant acknowledging that each of the others brings something valuable to the project and that their combined intelligence is more likely to deliver positive results than working in isolated silos. This can be challenging for architects, since a culture of pride in individual authorship is deeply ingrained in the profession.

Collaboration requires considerable skill and commitment from both parties. It is the responsibility of the lead consultant to keep dialogue and design explorations progressing until the stage when critical consensus decisions, like agreeing on the final structural configuration, are made. Every team member must share the responsibility of and be satisfied that the chosen solution is best for the project and meets his or her professional standards before moving on.

Experience shows that for collaboration between architects and engineers, 'earlier is better'! This is especially true at the conceptual stage of a project where those critical project-shaping decisions are often very difficult, costly, or inefficient to change. At this stage of a design, architects should share their design aspirations with the design team and obtain advice regarding structural systems during their design iterations. Required input includes advice regarding structure to resist earthquake forces and geotechnical conditions. Decisions made at this time become the conceptual framework for future design development. The ramifications of these early decisions profoundly affect the success of a project as measured by many factors. These include cost, day-to-day functioning and disaster performance in a fire or earthquake. Only the most experienced engineers possess the necessary expertise to provide advice at this stage of a project. In some cases, a brief conversation between architect and engineer may be all that is required to ensure the implementation of sound engineering strategies able to be developed in later phases. However, for more complex projects there could be many design iterations.

During the preliminary design phase, decisions made earlier are reviewed and given more extensive consideration to the extent they can be communicated on drawings; first to indicate how structural and mechanical engineering systems can be integrated, and secondly to show how they integrate with the primary architectural objectives. This phase, and those following, require an increasing degree of coordination between architectural and engineering documentation.

Successful collaboration is characterised by an open and trusting culture. Engineers and architects must be open with each other regarding their design aspirations and concepts. They need to communicate with each other what they are hoping to achieve. Engineers should actively seek to determine the primary architectural design ideas if they are not clear to them, so their advice is the most relevant and applicable. Design team members must also trust each other to maintain their individual professional standards whilst working towards the best collaborative outcome.

3 RESIST SOFTWARE

For over 20 years various versions of RESIST have empowered architectural students to undertake preliminary seismic and wind designs for their design projects. RESIST overcomes the powerlessness students experience when needing to know how much structure is required to resist lateral loads. The program also enables them to very quickly get a feel for what structure is required in a given building, and to explore the various factors that affect the size of that structure, such as increased floor plan dimensions and weights of construction. Since students who use RESIST can design structural walls, moment frames and four different types of cross-braced frames, they become familiar with all principal lateral load resisting systems. Students are introduced to RESIST, where it is also used as a teaching tool, in a lecture. After this brief introduction, they are able to use the program in their own design projects. A huge benefit of the program is that it enables students to quickly explore many different structural solutions before arriving at the one that integrates best with their architectural design concept.

Experience with architectural students shows that if a structural tool like RESIST is too complex and time-consuming they will not use it unless forced to. The input required for RESIST is therefore kept to the bare minimum. No calculations are required. This deliberate simplification of input reduces the accuracy of the results slightly and leads to a number of limiting assumptions. These include a maximum height of eight storeys, all interstorey heights are equal, structural elements in one direction are identical, and only one structural system may be used in each direction, and it must be parallel to an orthogonal axis.

RESIST enables designers to determine the numbers and sizes of earthquake and wind load resisting elements in buildings at a preliminary design level of accuracy. It undertakes structural analyses using approaches and assumptions similar to those of an experienced structural engineer during a preliminary structural design. RESIST's user-friendliness and compelling graphic features makes it invaluable and popular among architectural students. Although the software has undergone several technical and format upgrades over the years, it has maintained these unique qualities of simplicity and user-friendliness. RESIST can now be freely downloaded from the Ako Aotearoa website: https://akoaotearoa.ac.nz/resist.

Users begin their designs by defining the dimensions and shape of their building using the Floor Plan Editor, and then choose either 'heavy', 'medium' or 'light-weight' construction for walls, floors and roof (Fig. 1). They then select the building Importance Category, the soil type and the seismic Hazard Factor from an on-screen map before inputting several other factors that enable the program to calculate earthquake and wind loads. In the next phase of the analysis and design process, users choose one lateral load-resisting system for each orthogonal building direction. For example, moment-resisting frames might resist loads in one direction, and structural walls in the other. Structure in reinforced concrete, steel or timber may be designed. After choosing the numbers of bracing elements in each direction and estimating their size, the Results screen displays bar graphs showing how the key structural indicators, bending and shear strength and drift (horizontal sway) compare with code requirements (Fig. 2). If structural actions exceed the maximum values allowed by the code, the structure is under-designed. Structural member sizes must therefore be enlarged or more members provided.

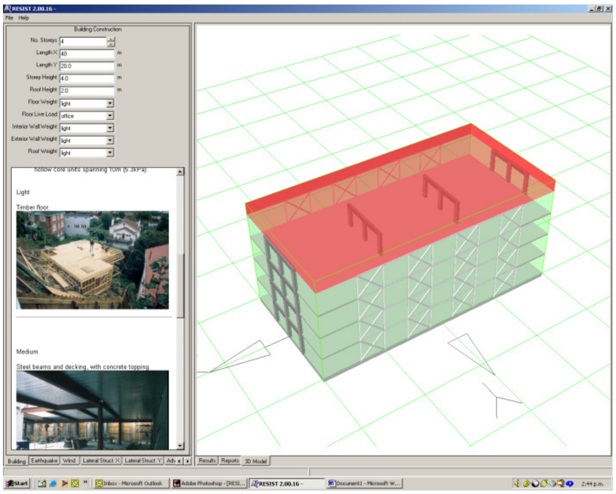

Figure 1. A 3-D image of building being designed using RESIST. Reinforced concrete moment frames act transversely while longitudinal loads are resisted by separated single bays of steel cross-bracing.

Calculation results are expressed as bar graphs (Figure 2). Usually, several iterations involving modifying the numbers and sizes of structural elements are required. After completing a design, users can access more specialized information such as foundation sizes and the maximum sizes of openings permitted in structural walls. A simple (Architectural) report that includes an image of the structure can be printed off to summarize the design, or alternatively an Engineering Report is available if a user requires detailed technical information.

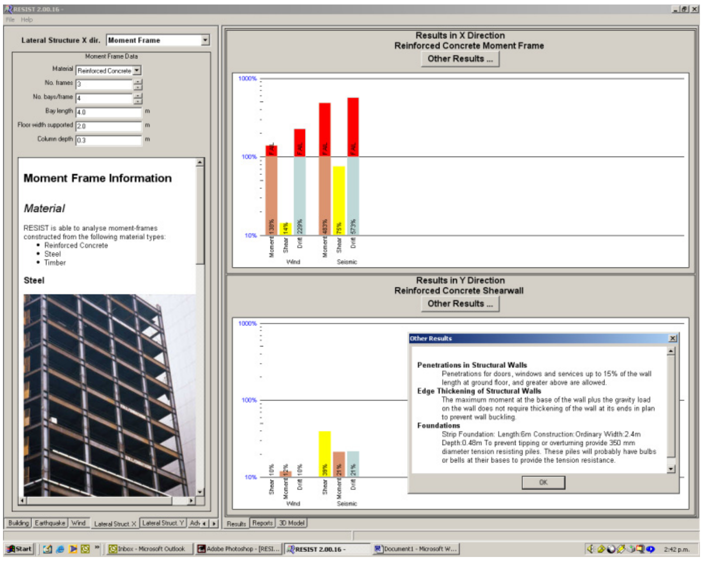

Figure 2. The Results screen. Red bar graphs indicate that the design is not code-compliant.

For detailed technical information about RESIST, readers should consult the manual provided within the software (Charleson and Wood 2014). The latest version of RESIST has been updated to NZS 1170.5 (Standards 2004) and includes interim guidance information subsequent to the 2010 and 2011 Canterbury earthquakes (SESOC 2013) as outlined in the online manual. Other enhancements allow for irregularly-shaped building plans, accurate torsion modelling and incorporation of other features to improve usability. The current version of RESIST is force-based, and progress has already begun on a displacement-based version.

4 COLLABORATION USING RESIST

A survey of architects and engineers reveals that engineers value architects' structural understanding (Charleson and Pirie 2009). Structural knowledge enables architects to appreciate and contribute to engineering issues under discussion. Engineers also greatly value having their structural advice sought early, rather than too late for them to make a significant positive difference to a project. Architects noted both how they welcome engineers' innovative approaches rather than just conventional solutions, and when engineers engage with the architectural design ideas. Therefore, given these findings, it is likely that RESIST can improve collaboration on several different levels.

First, RESIST can improve architects' structural knowledge. When architects use RESIST on one of their projects and investigate various seismic-resisting options, they will quickly increase their knowledge of the type and amount of structure required. Consequently, they will be far better placed to participate in productive conversations with a structural engineer. Subsequent structural refinement by both architect and engineer using RESIST together might then be completed relatively effortlessly. Secondly, RESIST enables engineers to investigate more innovative schemes. Its ability to very quickly assess the suitability of a number of different seismic systems and configurations means that many options can be explored, including less conventional approaches, leading to innovation. RESIST's contribution to structural innovation will not be through highly technical aspects, but mainly in the area of structural configuration. Finally, once engineers understand architects' underlying design concepts, they can quickly explore the implications of structural systems that might not normally be considered, but could yield particularly elegant structural solutions.

The following approaches are suggested in order for RESIST to make the best contributions to architect-engineer collaboration. Ideally, architects should use RESIST as soon as they have an idea of building massing, and before they begin detailed space planning. At this early stage in their design they will be able to integrate the seismic structure not only with their design concept but also with other architectural concerns, like circulation and functionality. Architects should explore a few structural options and prepare lists of questions and discussion points to raise with structural engineers.

Next, an architect and structural engineer should use RESIST together. The architect could begin by presenting his or her RESIST findings to the engineer. At this stage, the engineer can assess the accuracy of the architect's designs and critically review the breadth of structural design work undertaken. Then refinements to the original designs can be undertaken, and new configurations investigated from both viewpoints of engineering and architectural suitability.

The engineer will also be able to add a lot more value to the RESIST results. Perhaps some of RESIST's assumptions are inappropriate for a particular building; perhaps the foundation conditions suggest a particular approach; or that the high levels of interstorey drift may lead to unacceptable architectural detailing, including wide separation gaps between building and site boundaries and structural and non-structural elements. The engineer will also introduce other considerations well beyond RESIST's capability, such as the feasibility of certain diaphragm penetrations, the speed and cost of construction, and issues like the feasibility of post-earthquake repairs. There may be a need to mix structural systems. This is outside the scope of RESIST.

Using RESIST as a collaborative design tool, with architect and engineer designing together, structural options can be explored very quickly. Many iterations can be undertaken without the engineer having to spend hours or days calculating back in his or her office. The final preliminary design might be agreed upon subject to both parties allowing some quality time for reflection, and in the case of the engineer, independently checking the results of the RESIST analyses.

5 CONCLUSION

One of the key features of architect-engineer collaboration is the need for structural engineers to adapt to and participate in architects' iterative design approaches. The RESIST software, suitable for the conceptual or preliminary stage of a building design, facilitates any number of iterations to explore different numbers, types and configurations of seismic load-resisting structural systems.

6 ACKNOWLEDGMENTS

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