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Curtain Wall Enginering

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SUMMARY Curtain walls are the most abused of building elements being subjected to wind loading, extreme events, building movements, sudden temperature changes, driven rain, atmospheric pollution and corrosion. This paper discusses the need for a better technical awareness in curtain wall design through a much greater involvement of the structural engineer. Experience by the authors has shown that there are many deficiencies. The deficiencies include: too great a reliance by the designers on the performance specification, the potential of differential movement between the building and the curtain wall causing the glass to crush or the window fall out, the creep shortening of concrete structures, the proliferation of the new technique of structural silicone glazing without proper quality control of installation and adhesion, or the potential of falling glass due to wind effects. This paper seeks to identify how the quality of facade design and construction can be improved.

1. INTRODUCTION

A visit to any major city throughout the world will usually reveal a great many buildings having glass curtain wall facades. However, how many people will stop and consider the process by which that curtain wall was developed and question whether the current popularity of these facades is supported by sufficient technical expertise? The experience of the authors in this field leads them to conclude that there are many deficiencies.

In Australia, it is usual for a curtain wall to be developed from a particular curtain wall system that has been designed by a curtain wall contractor. This approach is an extension of the traditional approach to window installation.

In accordance with this approach the role of the structural engineer has been typically a very limited one and has been two fold.

In the first instance, the role of the the structural engineer is as the Building Design Engineer. Here his contribution to the design team has been limited to computation checking of a typical curtain wall fixing detail, in response to an invitation from the architect.

In the second instance, the role of the structural engineer is as the Contractor's Structural Engineer. Here his contribution to the design of the curtain wall has been limited to the production of computations in response to a performance specification. This will be the minimum that the curtain wall contractor perceives necessary to satisfy the architect.

Both of these situations are inadequate. They need to be strengthened by having a major input from a structural engineer, either within the building design team or in support of the curtain wall contractor when designing the curtain wall.

This need is particularly important in the area of structural silicone glazing. Here the glass is stuck onto the substrates with silicone. Understandably, considerable concern about the long term reliability of this technique has been expressed by many people. Increased confidence can be achieved by involving the structural engineer more in this process.

The authors have had some ten years experience in curtain wall design through a range of projects and have been engaged in both of the structural engineering roles described above. This experience has demonstrated the need for a greater awareness by both designers of buildings and curtain wall contractors of many aspects of facade design and construction.

The authors believe that the best way to strengthen this awareness is to have the structural engineer in a key position within the building design team so that he can evaluate and unify the many fragmented and often uncoordinated contributions from specialists and suppliers.

This paper seeks to analyse the traditional approach to curtain wall design and identify areas where the approach should be improved. It concentrates on the role of the structural engineer as the Building Design Engineer. However, appropriate reference is made to the role of the Contractor's Structural Engineer.

2. THE PERFORMANCE SPECIFICATION

The way in which the curtain wall industry is structured is such that it is not feasible to design and document a curtain wall and then call tenders. Instead, the curtain wall is developed based upon a performance specification.

The performance specification is a document which requires the curtain wall contractor to design the curtain wall using conceptual architectural drawings, and the specified design criteria contained within the specification. The performance of the curtain wall is required to be guaranteed by the curtain wall contractor for a period of between 5 and 15 years.

Through this performance specification the architect abrogates his traditional role of design, and a document is produced which often relies far too heavily upon the curtain wall contractor. The performance contract has produced an attitude that only the end product matters.

The performance specification also promotes a "hands off" mentality by both sides, when individual elements of the curtain wall are brought under close examination. There is difficulty in deciding where individual quality starts and when the end performance overides if individual elements fail to meet minimum standards of quality.

The performance specification is therefore an important document. The aim of the document is to ensure that designers, contractors and building owners fully understand the demands for design, weather proofness, quality control, supervision and future maintenance. The document should include minimum technical standards to be met by individual components and materials.

In order to write such a specification, the building design team, must address the specialist areas of curtain wall design and understand the complexities of the task. It is essential that interfaces between specialist and materials are analysed and responsibilities clearly defined.

The structural engineer is in a good position to evaluate technically the contributions of the many specialists, ensure that they are compatible with each other, and then successfully incorporate them into the design. It is in this broader role that the structural engineer's greatest contribution lies.

3. THE CURTAIN WALL TEAM

The specialists that make up the curtain wall team and the technical areas that must be addressed are many and varied. The list below identifies the specialists that are likely to be involved:-

Building owner;
Architect;
Structural engineer;
Mechanical engineer for thermal performance;
Building authorities;
Builder;
Curtain wall designer;
Curtain wall fabricator;
Curtain wall erector;
Glass supplier;
Glazier;
Applied finish supplier;
Applied finish applicator;
Sealant supplier;
Sealant installer;
Testing laboratory;
Fire proofing contractor;
Building maintenance unit supplier;
Installer.

The areas likely to be addressed by the team fall into the following broad categories:-

Authority requirements;
Design loadings and code requirements;
Engineered solutions and structural systems;
Material quality investigations and controls;
Prototype testing;
Limiting air leakage and water penetration;
Sealant detail, selection and installation;
Durability aspects;
Corrosion between dissimilar metals;
Fabrication and erection aspects;
Attachment to the buildings;
Movement of the curtain wall;
Movement of the curtain wall relative to the building;
Inspection and maintenance.

It is the failure to understand the complexities of the task and attend to the matters listed that leads to problems being experienced in the future.

4. STRUCTURAL ENGINEERING

The Building Design Engineer's contribution has traditionally been restricted to checking computations of typical unit fixings to the structure in a most minimal way. The Contractor's Structural Engineer is often employed on a limited basis to check stresses and deflections in the main components. There is often no overall review or engineering evaluation of non-typical areas, connections, or technical input by other component suppliers.

However, with the rapid growth of the curtain wall industry and the relatively recent introduction of structural silicone there has been greater involvement by the structural engineer.

The key areas of structural engineering involvement should be:-

1. To design of all individual elements and their fixings to adequately withstand the applied stresses without excessive movement.

2. To understand the structural behaviour of the building, such as creep and shrinkage, so that it can be incorporated into the design of the curtain wall.

3. The investigation and technical examination of the various materials to be used in the curtain wall. These include aluminium, anodising of aluminium, painting of aluminium, stainless steel, glass, glass coatings, silicones, gaskets and material separators.

4. To comment on and advise on proposals and procedures where structural silicone is utilised.

4.1 Structural Design

The curtain wall system must be designed so that it obtains support but is not subjected to any loading from the building.

It is usual for a curtain wall to be developed from a particular curtain wall system that has been designed and marketed by the curtain wall contractor. This design is often a typical panel solution that utilises members and design details that are an evolution of the contractor's practice. Most buildings are different in floor to floor height, column grid, plan shape, structural and spandrel depth. It is therefore necessary for the basic proprietry systems to be adapted and designed for each case. The curtain wall design must cover not only the typical panels, but also address the intersection of panels and the resulting two-way joints that occur.

The curtain wall must be designed for wind loadings, including the local suction factors at the building discontinuities. (Figure 1). Wind loading diagrams which define design wind pressures should be included in the specification. It is not satisfactory to specify a terrain category or a Code reference, since the curtain wall contractor may not possess the engineering knowledge to correctly access the wind pressures. This may lead to argument about interpretation. Wind loading diagrams for large or complex buildings may be obtained, with the assistance of a wind engineer, from the testing of a model in a wind tunnel.

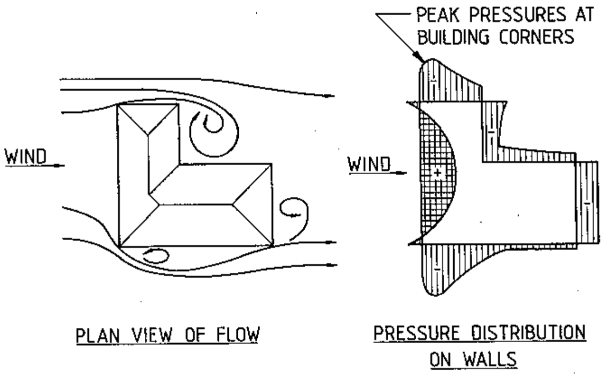

Figure 1 An example of pressure distribution on a building

4.2 Structural Behaviour of the Building

The Contractor's Structural Engineer must understand the structural behaviour of the building to which the curtain wall is to be attached.

All materials deform under load. In the case of concrete buildings, concrete deformation continues with time as the building is constructed or undergoes long term shrinkage and creep under load. The Building Design Engineer must state, within the contract documents, the anticipated short and long term deformation of beams and columns supporting the curtain wall.

The long term shrinkage and creep of columns and walls can result in floor to floor heights being reduced by some 3mm in a 3m height, after the curtain wall has been installed.

The detailing of curtain wall joints is particularly important where there is a potential for long term differential deflection of beams. This will occur where the floors above or below are rigid, such as at ground floor level or under stiff roof parapets. This must be highlighted by the Building Design Engineer. Failure to do this is a common cause of problems. In the case of the stiff structure below, the structure above deflects, the movement joints close, eventually the glass breaks! In the case of a stiff structure above, the structure below deflects, the movement capacity of the joint is exceeded, and the glass falls out. (Figure 2).

The curtain wall fixings must be able to accommodate the total differential movement between the curtain wall and the building without distress. These movements include building movement, temperature and sway. Temperature movements of the various materials can differ dramatically, and designers must acquaint themselves with these.

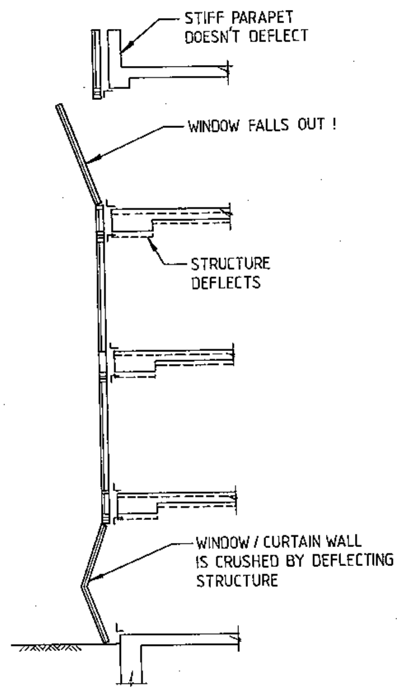

Figure 2 Building movements

4.3 Specification of Materials

The materials to be used in the curtain wall must be clearly specified. The specification must include minimum technical requirements, plus testing to support compliance with minimum standards and precautions to be taken to prevent corrosion attack through contact of dissimilar materials. The materials and the joint design are particularly important where movement is likely to occur. The joints must prevent water penetration, air leakage and be capable of movement over a period of many years.

The understanding of maximum acceptable member deflections is important. This is best done by the Building Design Engineer. This applies both to glass and glass supporting members. It is important to note that the Glass Installation Code AS 1288 does not specify limiting deflections. It is generally understood by the glass industry that span/90 for annealed glass and span/60 for toughened glass is an acceptable deflection under maximum wind load. This figure can lead to unacceptable flexibility in the glass under everyday wind actions. Similarly when building occupants touch the glass and find it disturbingly flexible, then the glass is too thin, even though it is adequate in strength.

The authors believe that the current situation is unsatisfactory and action should be taken by the Standards Association to have this matter included in the Glass Installation Code.

5. CONSTRUCTION

The erection of a curtain wall involves work in an environment which can lead to low quality workmanship and the absence of the normal levels of supervision and inspection.

The quality control that is carried out on general building elements in terms of testing of materials and inspections by clerks of works, architects and engineers is accepted as standard practice. However, this degree of quality control and inspection is rarely provided on facade elements that are in fact subjected to far more severe conditions. The perimeter of a tall building and the facade beyond is a psychological barrier which many people do not overcome. As a result, the outside of a building is often not inspected at all. Experience on many buildings has shown that where supervision is not carried out the quality of workmanship deteriorates.

The connection details for the fixing of the curtain wall to the structure should be designed for minimum abuse by the erector ie. by achieving simplicity and repetition. The proper level of supervision must be carried out both in the curtain wall contractor's factory and on site.

6. STRUCTURAL SILICONE GLAZING

Structural engineers prefer facade elements to be mechanically restrained and they have a built-in distrust of adhesives. However, the increase in use of structural silicone, particularly on higher buildings, requires that structural engineers become fully involved to ensure that the best results are obtained from the systems. This is best achieved by learning about the products, drawing on the expertise of the manufacturers, recommending on and advising with regard to testing and monitoring procedures, and advising on maintenance programs.

Structural silicone glazing is the most recent technique for the installation of glass onto buildings. By removing protruding frame members, the restraint of the glass relies on the adhesion of structural silicone to the substrate. The success of structural silicone is entirely dependent on the long term durability and adhesion of the silicone. Figure 3 demonstrates the many surfaces that may exist in a single joint that depend on adhesion.

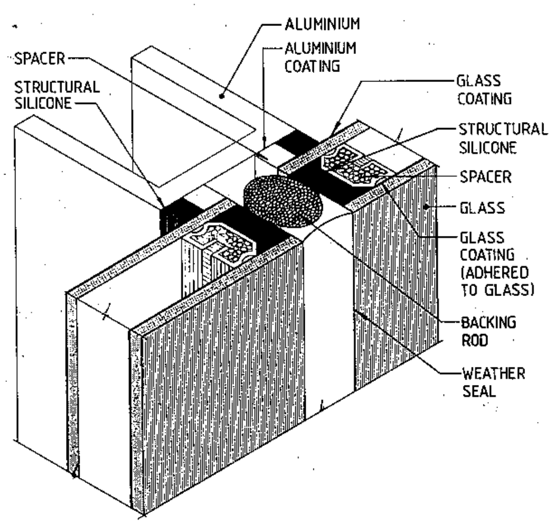

Figure 3 Structural silicone glazing detail

Structural silicone can be applied in the factory, which is known as factory glazing, or on the site, which is known as site glazing. A factory glazing system requires pre-fabrication of a sub-assembly including installation of silicone, which is then transported to the site and mechanically fixed to the building. On site glazing relies on installation of the glass and silicone on site. This is often done from a swing scaffold, which results in a lower quality of workmanship, greatly reduced supervision, and reduced inspection. Furthermore, it is difficult to maintain clean surfaces on a construction site. These are essential for good adhesion.

Structural silicone glazing is described as either two sided or four sided. Two sided means that the two opposite edges are supported by structural silicone, with the other two being mechanically restrained. Four sided means that all four sides are supported by structural silicone. As a back-up system to some projects utilizing four-sided structural glazing, patch plates have been mechanically fixed at the corners of each glass panel to provide mechanical restraint should the silicone fail.

6.1 Design of Structural Silicone Joints

The Glass Installation Code AS 1288 makes no reference to structural silicone glazing. The design and construction advice relies on testing and the expertise of the suppliers/manufacturers.

The dimensioning of structural silicone joints usually is based on an empirical (20 psi, 0.14MPa) working stress in the joint irrespective of the individual strengths of different sealants. This is the design method required by the sealant experts. Therefore, no matter how strong the sealant, the structural dimension is still the same. However, safety factors on ultimate strength of around 4 to 6 or higher in a laboratory situation are achieved by this approach. These safety factors allow for material inconsistency, local corner or edge stresses due to glass deflections, and human error in preparation and application.

6.2 Current Status

There is strong evidence that the concept of structural silicone glazing continues to be marketed without sufficient engineering review.

There is, as yet, no consistent body of information on the failure of silicones. There is also a lack of long term adhesion data for sealants adhered to different coated glass surfaces, and to the many types of metal surface finishes currently in use. These include anodised aluminium, and painted aluminium such as powder coated polyester and flouropolymer finish. It is time that the silicone industry carried out such research projects that are necessary to improve the knowledge in these areas.

The increase in use of structural silicone together with the marketing of the silicone companies leads many to believe that structural silicone glazing is a routine operation not requiring any special knowledge or techniques. This is not true. Within the industry there is a failure to fully appreciate the structural role of the silicone and there is a resistance to accept and adhere to techniques and constraints which are not consistent with "the way we have been doing it for years". This has the potential for serious problems.

Structural silicone glazing is an area where greater involvement of structural engineers is necessary. A recent development has been the requirement by some authorities in Victoria for certification of walls incorporating structural silicone by the structural engineer. The thrust of this certification is to try and ensure that structural engineers are fully involved in the curtain wall design and installation. authorities are also seeking to ensure that building owners, both present and future, have a responsibility to carry out regular inspections and maintenance of the facade. These authorities are seeking to be able to enforce this responsibility.

6.3 Quality Control and Assurance

There are several steps which need to be taken to achieve good quality control and assurance. These are as follows:

- The silicone supplier is the expert in the silicone technology and he must accept the role of establishing the correct sealant, the correct sealant use and the correct procedure for its installation.
- The silicone supplier must be called upon to review the curtain wall shop drawings and accept the manner in which his materials is being used.
- The silicone supplier must provide written project instructions for the use of the material and carry out inspections and supervision of its installation by suitably trained personnel.
- Testing must be carried out to ensure compatability of all components and to prove adhesion between all the required elements.
- On projects that the authors have been involved in, they have recommended laboratory direct tension testing of small and full scale samples to prove adhesion of silicone to individual substrates. Since there is no standard available for this type of test, they have developed a specification for this in conjunction with the sealant suppliers. The cost of these tests and the cost of sealant suppliers' input, must be allowed for in the pricing of the curtain wall.
- Installed glass must be cut out to observe the quality of sealant installation and to confirm that adhesion has been achieved. This is known as deglazing.
- Excellent workmanship is VITAL to the successful performance of silicone glazed curtain walls.

7. WARRANTIES

This paper does not address the subject of warranties, however the authors recognise the concern over warranties expressed by building owners, designers, manufacturers, suppliers and contractors. Without doubt, the best warranty for any project is to ensure that the job is carried out correctly in the first place. Too great a reliance on a warranty can lead to a false sense of security.

8. FUTURE INSPECTION AND MAINTENANCE

The type of materials that are used on building facades and curtain walls often do not have a sufficiently long history to warrant the lack of attention that is paid to them by building owners. An owner accepts that he must allow for replacing and maintaining plant, repainting internal walls, replacing carpet and other interior furnishing on a regular basis as part of his investment return studies. However, he expects the facade to last forever, and exercises little control on whether the facade, its joints and sealants are in good condition or not. Alarm is only raised when water penetrates, pieces fall off, or other serious distress occurs. Much litigation in the building industry is related to water penetration, break down of sealants and distress in other facade elements. Much of this can be reduced or eliminated by carrying out a regular inspection. In most instances an inspection, say six months after initial completion and certainly before the initial defects liability period expires and then possibly at two year intervals should suffice. The cost of this is small and it can prevent major problems from occurring.

At the completion of construction, the owner should be advised to carry out this type of inspection and also be advised on the warranties and durabilities of some of the products that he is wishfully thinking will last forever.

9. CONCLUSION

This paper has sought to review the current status of curtain wall engineering and to highlight areas where there are deficiencies.

The rapid growth in the curtain wall industry and in particular structural silicone has seen a greater participation by the structural engineer in curtain wall engineering. The structural engineer, through involvement in conceptual and final design has found himself in a key position to stitch together the sometimes fragmented input of the various parties involved in a curtain wall.

A greater acceptance by architects and curtain wall contractors of the contribution that can be made by the structural engineer can only lead to the strengthening of both sides of the industry and the improvement in the quality of the end product.