SYNOPSIS
The last 10 - 15 years have seen a considerable number of refurbishment schemes that have required full facade retention systems during construction. There is a general lack of guidelines available on the design of these temporary work structures. This paper aims to suggest a method of design which basically involves looking at the two principal stages involved: the development of a performance specification by the Consultant and the detailed design of the system itself by the Contractor.
1.0 INTRODUCTION

Under the provisions of the Planning Legislation the Local Authority is empowered to give statutory protection to buildings of architectural or historic importance. The architectural reasons for "listing" these buildings may be associated with the quality of the internal detailing and finishes. It is frequently the case, however, that the architectural significance lies in the external facades and these may be deemed the only elements of the building worthy of preservation. Many of the facades so listed today are part of 19th century buildings with substantial load bearing walls constructed using load bearing brick and / or stonework.

Inevitably, in the course of time, decisions have to be taken concerning the refurbishment of this type of building. This can take the form of either repair or maintenance of the existing fabric or, more radically, demolition of the internal structure with the external facades held in place throughout, followed by the erection of a new framework internally to which the original facade is then attached. Despite the comparatively high cost involved in choosing the latter alternative it is frequently the only commercially viable option available that will make the refurbished building marketable as a desirable modern working environment. The main reasons for this are as follows:

(a) The permanent partition layouts, typical in old buildings, do not have the flexibility required for modern use.
(b) The service zone in traditional buildings is usually minimal or non-existent. A new structural system is often required to accommodate modern services within the given floor zone.
(c) The new floor structure can be designed to have greater load capacity as typically required for modern usage.

For these reasons the last 10 - 15 years have seen a considerable number of refurbishment schemes that have required full facade retention systems during construction. There is a general lack of guidelines available on the design of these structures. This lack of information is particularly disturbing when one considers the vulnerable nature of these structures (which are often either statically determinate or have a low level of structural redundancy) and the serious risk to public safety attached to structural failure.

This paper aims to suggest a method of design for these structures. This basically involves looking at the two principal stages of design.

(i) Development of the Performance Specification. - By the Consulting Engineer.
(ii) Detail Design of the System. - By the Contractors Temporary Works Engineer.

2.0 SCHEME DESIGN AND PERFORMANCE SPECIFICATION

Generally the facade retention system, as a temporary works item, will be the Contractors design responsibility. These systems, however, have a vital role to play in ensuring both site and public safety for the duration of the contract. They are also often significant structures in their own right playing a major part in the financial success or failure of the project. As such they merit more careful consideration, by the design team, than that usually given to temporary works.

In any such scheme, therefore, the design team should address the problem of facade retention from the outset, giving it the importance it deserves as a critical element of the project. A careful feasibility study should be carried out and tentative retention schemes developed to meet the requirements of the brief. This exercise is important in determining that the facade can be retained in such a manner that the system does not create buildability problems that are either impossible to solve or are likely to impose too onerous a cost penalty on the final tender price.

The results of this tentative design process should be incorporated into a design brief / performance specification with which the contractor must comply. The choice of scheme and detail design is then left up to the contractor for him to decide which suits him best bearing in mind all the buildability aspects that need to be considered as well as the cost of the system itself.

The ideal, therefore should be to produce a comprehensive specification that states clearly the design parameters involved and the performance standard expected. The steps involved in producing such a specification are as follows:

(a) Desk Top Study.
(b) Preliminary Site and Building Survey.
(c) Scheme Design Options
(e) Detailed Survey and Site Investigation.

2.1 Desk Top Study

The first step in the design of a facade retention system is to assess the nature and extent of the problems involved in holding up the facade when the supporting internal structure has been demolished. This requires a global knowledge of the way the existing structure works along with detailed information concerning the facade itself. The study carried out should reveal the following:

1. The overall structural form of the building i.e. the method by which it carries vertical and horizontal loads to the foundations.
2. Details of the facade itself including wall construction (facing and backing materials) wall thickness, special features etc.
3. Details of the connection between the facade and the existing internal structure to clearly identify the method by which lateral restraint is provided to the wall.
4. Existing foundation details such as size, depth and estimated bearing pressure.

All this information can best be obtained from examination of the original construction drawings for the building. In most cases, however, these will have been mislaid over the years and will be difficult or impossible to obtain. It should be emphasised, however, that it is well worth putting considerable effort into unearthing this documentation as it will substantially reduce the extent of the time consuming site survey required later.
Clues to construction may also be given by:

5. The approximate age of the building. (as there is information available on past construction practices this can be useful as a guide to the likely materials used, minimum wall thickness etc.).

6. Architectural Type - e.g. the structure of a Typical Georgian House is well known.

2.2 Preliminary Site and Building Survey

The extent of the site and building survey required will largely depend on the success of the desk top study. If no documentation is available then an extensive survey will be required to provide the information discussed in 2.1. Even if comprehensive "as built" drawings are to hand, it is prudent to carry out a series of spot checks to confirm their validity. These should include breaking out finishes to examine key structural elements. The preliminary survey should also provide the following information:

1. The condition of the facade walls and the nature of any major defects. In particular it is important, at this stage, to identify the problems involved in making the final connection between the wall and the new permanent structure. Brick facades, for example, may have weakened considerably over the years and the interface connection details between old and new will have to be very carefully considered.

2. Details of any alterations to the building which have affected the facades (e.g. additional storeys, new openings, etc.).

3. Details of any special facade features, especially those that are eccentricity supported and rely on the internal structure for their restraint.

4. The nature of any site constraints that may affect the location and design of the temporary works, e.g. road, footpaths, below ground services, etc. If these are present within or adjacent to the site boundary they may have a fundamental effect on the siting of the vertical elements and foundation knowledge for the system. Careful liaison with the local authority and public utilities involved is required to arrive at a mutually acceptable scheme.

5. The likely site access location. Even at this early stage it is important that this is considered especially if large plant such as piling rigs, are required whose access requirements could have a major effect on the siting of the temporary works.

6. The likely party wall problems involved. It may be possible to use these walls to support flying shores. On the other hand they may themselves require temporary shoring during construction which could have a bearing on the location and type of retention system used.

2.3 Scheme Design Options

When the desk top study and preliminary survey have been completed and the information evaluated it will be possible to confirm or otherwise the suitability of the facade for retention. Any proper assessment of the feasibility of the project will involve looking at the scheme options available and these are described in 2.3.1 to 2.3.4 below in terms of extent, location, structural form and foundation requirements.

2.3.1 Extent of Retention System

The first consideration in the design of any scheme is to assess the extent of system required. It may be possible, for example, to avoid temporary works altogether by erecting the perimeter bay...
of the new permanent structure prior to extensive demolition and, in effect, use it as the facade retention system.

Temporary works could also be minimised by judicious retention of some of the return walls and bracing the facade off these as required to compensate for the removal of the floors. Similarly, larger flying shores could be used to restrain the facade off boundary walls not affected by the demolition (see Fig 1).

2.3.2 Location

If the options described above are not available a full scale facade retention system (i.e. with its own independent foundation) will be required. For any such system the first decision to be made is regarding this location - i.e. external, internal or combined.

External systems have the obvious advantage of freeing the site of obstructions thereby minimising the problems involved in constructing the permanent works. Their use, however, is often prohibited by the Local Authority involved because of their impact on public footpaths, roadways, services etc.

Internal systems are generally not subject to such restrictions, they do however, require careful planning so that they can be installed prior to the bulk of the demolition taking place. The siting of what is usually a heavily latticed structure in the area where the permanent structure is to be erected will also inevitably restrict both manoeuvrability and buildability.

On rare occasions combination schemes are used which are for the most part external but where either some or all of the framework below first floor level is internal. These overcome the usual objections to external schemes while minimising the internal problems. The structure is inherently more complicated than for the more straightforward systems and the benefits gained should be balanced against the increased system cost involved.

2.3.3 Structural Form

There are three basic structural forms which can be used both externally and internally.

1. Horizontal walings and raking shore system. This is essentially a development of the timber raking shore support traditionally used to prop up unstable walls, the difference here being that the system must also provide a tie reaction to prevent the facade falling away from the shore. Because of the space required for the raking member this system is normally confined to low rise situations.

2. Horizontal walings with closely spaced steel frames (see Fig 2). This system provides vertical steel frames at relatively close centres to support the horizontal walings. These frames are typically comprised of a haunched portal frame ground to first floor, allowing through pedestrian access, with a stiff cross braced vertical cantilever truss above first floor level to minimise lateral deflection. If through access is not required the portal can be replaced by cross bracing to ground level. Cross bracing is also provided in the longitudinal direction for stability. This system is particularly suited to the use of proprietary components as will be discussed further in Section 3.11.

3. Horizontal truss walings and vertical towers (see Fig 3). Where design constraints prohibit close regular spacing of vertical elements it may be necessary to use stiff trussed horizontal walings spanning between vertical cantilever box towers. If there are stiff vertical elements, such as flank walls or services cores, already available on site, these may be used in place of the towers in a variation of this scheme.

The above options are all principally concerned with the provision of lateral restraint to the retained facade. There may, however, be a requirement for temporary vertical support to eccentric elements such as overhanging features, balconies etc. originally restrained by the internal structure. These can be supported using vertical "dead" shoring incorporated into the overall scheme (see Fig 2). On a larger scale there may be a need to provide temporary vertical support to the facade proper and this can be accomplished by using the framing beams as needles at whatever level required. Another common requirement is for high level site huts to be incorporated into the design and this can generally be accommodated by minor adjustments in the bracing layout.

2.3.4 Foundations

The foundation for a retention system is principally required to resist the overturning and sliding caused by the lateral forces on the wall. It must also be capable of transmitting the vertical loads to the ground below without unacceptable settlement. While this is not usually critical there are occasions when particular care should be taken. If, for example, the legs of the vertical frame are at different levels (as is often the case when on different sides of the wall) there may be a possibility of differential settlement. This can cause tilt of the base which will be magnified many times over at the top of the frame.

While the problems of settlement need always to be considered they are not usually critical and generally the main foundation problem is in providing adequate kentledge to resist overturning and sliding. With an internal scheme it may be possible to use the new foundations for the permanent structure as ballast for the temporary works. This, however, depends on whether the necessary foundation work can be carried out prior to the bulk of the demolition taking place. On many sites this sequence of construction will not be possible and the kentledge must be provided by more direct means such as casting concrete around the feet of the frame. It is important to have an idea of the size of kentledge required at an early stage as space restrictions can often be critical and, if possible, use should be made of the wall self weight to minimise the amount of ballast required (see Fig 2). If ground floor space is to be maximised the bulk of the kentledge could be placed at first floor level at some cost to the structure below.

Alternatively the size of foundation could be reduced by modifying the structural system used. If, for example,
stiff vertical elements of inherent weight (such as flank walls) exist on site these could be used to provide lateral support to a horizontal truss installed at roof level. The vertical cantilever frames could then become vertical beams thus reducing the foundation role to that of resisting sliding and transferring the overturning problem to the flank walls.

With tower systems the foundation problems are increased because of the concentration of the load into an isolated element. Very substantial foundation kentledge will be needed in these cases and, for tall tower systems, it may well be that a tension pile foundation is the only practical solution. Basement sites also have the additional problem of temporary propping to the retaining element while the ground and possibly subground floors are removed. These props might be incorporated into the facade retention framework or alternatively may form an independent shoring system with its own separate foundation.

The pressures for which these shores should be designed can be quite high (see Section 3.3) especially when large foundation kentledge is placed externally.

2.4 Detailed Survey and Site Investigation

When scheme evaluation has been completed it may be necessary to return to the site and carry out further investigations with tentative schemes in mind. This will be a more purposeful visit with items of particular importance to the scheme identified and examined in greater detail. In addition, the following information will be necessary for detailed design:

1. Dimensional survey of the facade and existing structure. This should include overall length and height, wall thickness and dimensional details of any cross sectional variations, floor and ceiling levels, window and door locations and sizes.

2. Plumb survey results to assess any existing lack of verticality in the wall. Any overhanging eccentrically supported features identified in the preliminary investigation should be surveyed in detail, at this stage, to give adequate information for dead shore design.

3. A full schedule of condition of the facade including a comprehensive photographic survey. This is vital as a pre-demolition record of the state of the wall. All defects should be noted and if a repetitive problem is evident (e.g. corroding embedded steelwork, decaying bond timbers etc.) the temporary works should be so designed as to facilitate any remedial work that needs to be carried out. Any areas where serious deterioration is present should be identified and the option of careful demolition and rebuilding considered if the authorities are agreeable.

4. Test results for permanent fixings. It is advisable, at this stage, to carry out tests to assess the performance of the intended permanent fixing system so that any design changes can be incorporated in good time.

5. A full Site Investigation, including existing foundation details. This will usually have been carried out as part of the investigation work for the permanent structure and should be included as part of the design brief for the temporary works.

It should be mentioned, however, that no matter how detailed and comprehensive the survey carried out something relevant will almost always be missed. Many defects, in fact, will not be visible until towards the end of the contract when the facade has been cleaned. It is strongly recommended, therefore, that a sensible contingency sum is included in the project cost to allow for problems unforeseen at tender stage.

2.5 Performance Specification for Detailed Design

At this stage all relevant information for the design of the facade retention system will have been assembled and the consultant will have a tentative scheme or schemes in mind which he is confident will work within the limits of the cost plan. This information can now be presented as a tender package which will outline clearly to the Contractor all the design parameters involved and the performance standards expected. It is then up to the Contractor to satisfy himself that the proposed scheme is feasible and to carry out the detailed design or alternatively put forward his own proposals to meet the required specification. The overall cost impact of any facade retention system is highly sensitive to the construction problems caused by its presence and, as the Contractor is best placed to assess these, he should be free to pursue the design he considers most cost effective.

The performance specification, therefore, should firstly give a concise presentation of the matters discussed in 2.1, 2.4 in terms of their impact on the design parameters for the retention system.

In addition to the above the specification should:-

- Give explicit loading information for wind, eccentric, retaining, accidental and vertical loads - see sections 3.1 to 3.5.
- Give lateral deflection limits for the structure under load - see section 3.7.
- Describe any finishing treatment required (there may be Planning Conditions re painting)
- Give instructions on the method of demolition allowed, e.g. ball demolition prohibited and hand demolition only adjacent to the facade.
- Request a method statement to show the intended sequence of operations involved in demolition, erection of the retention system and construction of the permanent works with the system in place.
- Outline the procedures involved in approving the contractor's design, i.e. specifying approval periods, design responsibilities etc.

This performance specification could be presented as a written document forming part of the overall engineering specification for the job with the suggested scheme design given in sketch form. Alternatively, it could be presented as a tender drawing with the specification in note from. Either way the emphasis should be on clear unambiguous presentation so that the contractor is in no doubt as to the
design criteria or the performance standards expected.

3.0 DETAIL DESIGN CONSIDERATIONS

There is no British Standard available that specifically covers the detailed design of facade retention systems. Strictly speaking they comply with the definition of falsework given in BS5975 (Code of Practice for Falsework) as a "temporary structure used to support a permanent structure while it is not self-supporting". The introductory section of this code, however, points out that some structures embraced by this broad definition, such as shoring, are not within its scope. It refers the reader to CP2004 (now BS8004) for further information. It also refers to BS5973 (Code of Practice for Access & Working Scaffolds and Special Scaffolds) for guidance on design of such shoring.

The sections on detailed design that follow, therefore, have been compiled by examination of these and other relevant British Standards and associated publications in order to formulate an appropriate design approach.

3.1 Lateral Loads Due to Wind

The basic reference document used in assessing the wind load on any structure is CP3: Chapter V: part 2. The load is typically built up in a three stage process, the first step being to calculate the dynamic wind pressure "q" which is then modified by the appropriate force coefficient "Cf" and applied to the effective area normal to the wind to give the load.

3.1.1 Determination of the dynamic Wind Pressure

In following the procedure for a facade retention system "q" is firstly calculated using a statistical factor S3 based on the period of exposure and the acceptable probability that the wind will be exceeded. Traditionally, for temporary structures, S3 is taken as 0.77, corresponding to a period of exposure = 2 years and a 63% probability of exceedance. This effectively means that in 2 out of 3 projects the wind load will be exceeded. This is not so important in designs where deflection is not critical as the partial load factors for the ultimate limit state will effectively reduce the probability of exceedance to more acceptable levels. Facade Retention Systems, however, are typically deflection critical where the 63% probability that the unfactored wind load, and hence deflection limit, will be exceeded would not appear to be acceptable.

It is recommended, therefore, that when checking overall deflection limits that an S3 = 1.0 is used as this reduces the probability of exceedance to 5% approximately. Design for ultimate limit state can still be done for S3 = 0.77 as the factors of safety used here effectively reduce the probability of exceedance to acceptable levels.

3.1.2 Determination of Force Coefficients

The determination of "Cf" is complicated due to the compound nature of the structure which is part open frame-work / part free-standing wall.

The wind force on the stabilising system is the sum of the forces on these two separate components, i.e. the load on the frame itself plus the load on the retained wall transmitted to the frame through the walings. While it is relatively straightforward, using CP3, to calculate the force on either of these elements in isolation, there is no proper guidance given on the method of assessment when the two are tied closely together. Of the two, the wall will usually be by far the more significant obstacle obstructing the flow of the wind and will therefore tend to reduce the effect of the wind on the individual frame elements. The scaffolding Code BS5973 gives a detailed method for calculating these forces that takes into account the effect of wall openings (windows etc.). This method, however, is complicated and depends on the air flow through

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**Table: Actual length/height ratio of wall (L/H)**

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<th>2</th>
<th>4</th>
<th>6</th>
<th>8</th>
<th>10</th>
<th>20</th>
<th>40</th>
<th>60</th>
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<td>1.24</td>
<td>1.30</td>
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<td>1.62</td>
<td>1.65</td>
<td>1.74</td>
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<td>B</td>
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<td>1.36</td>
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**Fig. 4**
these openings remainings unhindered for the duration of the temporary works. Section 3.1.3 that follows outlines a simpler, more conservative procedure that does not impose these restriction and which will, therefore, be appropriate in most cases.

3.1.3 Simple Method

A simple method for determining wind loads on Retention Systems is suggested by BS5973 which states that the total force on a scaffold should not be greater than that which would be generated by an imperforate surface perpendicular to the wind. In the direction perpendicular to the wall this would be the equivalent of ignoring the effect of any windows and treating the retention system and wall as a single plate element. This could then be idealised as a free-standing wall and the total force calculated using the guidelines given in the Table 11.14 of the Wind Load Handbook (see Figure 4). This method is based on Section 8 of CP3 and gives force coefficients typically varying from 1.2 to 2.0 depending on the dimensions and end conditions of the wall.

In the longitudinal direction the scaffold would be assumed to be fully sheeted, resembling a long rectangular clad building, with the force coefficient given by Table 10 of CP3.

In most cases this method would probably be quite conservative especially where the openings in the wall are large and numerous. It does, however, allow for any blocking in of these openings that may be necessary to strengthen the wall. It also provides good cover for the effects of sheeting, hoardings, hutting, etc. attached to the retention system and is therefore a prudent approach to adopt when these items are not clearly defined in advance.

3.1.4 Recommendations

In summary it is recommended that wind load should be assessed as follows:

1. Calculate the dynamic wind pressure "q" using CP3 with $S_3 = 0.77$ for ultimate limit state and $S_3 = 1.0$ for the deflection check.


(a) Simple Method - appropriate for most cases.

(b) Detailed Method - BS5973 - has advantages in facades with many window openings but can only be used on rare occasions if it can be guaranteed that windows will not be blocked in or the system sheeted.

3.2 Lateral Loads Due to The Self Weight of The Wall

In calculating the total overturning moment for which the retention system must be designed allowance must be made for the lateral loads due to the self weight of the wall. These are due to two principal effects:

(a) Out of plumb distortion of the wall.

(b) Provision of buckling restraint to the wall.

Out of plumb distortion of the wall will be due to the following:

1. Existing out of plumb distortion of the wall that has occurred over a number of years. This is measurable and should be included as part of the brief in the performance specification.

2. Post demolition out of plumb movement caused by lateral deflection of the retention frame work due to:
   - The horizontal load required to prop the wall against overturning caused by 1.
   - Wind Loads.

Buckling restraint to the wall will be provided by lateral restraints capable of resisting a horizontal load equal to 2.5% of the vertical load in the wall at that level.
3.2.1 Traditional Method

Traditionally allowance for these two effects has been combined by designing for a blanket horizontal load of between 2.5 - 5.0% of the self weight of the wall.

Examining the lower bound 2.5% figure, this is equivalent to a wall 1 in 40 out of plumb which, when translated to storey heights, gives out of plumb values of between 125 - 500mm for walls of between 2 to 8 storeys high (see Fig 5). Designing for such high nominal eccentricities seems unreasonable unless plumb survey results suggest otherwise and, in which case, it might be more appropriate to rebuild rather than retain the wall.

The argument for 2.5% as a minimum requirement for lateral restraint against buckling is valid only on an individual waling basis as it would seem unnecessarily conservative to design the overall structure to take all these forces simultaneously - the more walings the more horizontal load.

3.2.2 Proposed Method

Modern limit state codes address the problem of lack of verticality more directly and require structures to be checked for notional horizontal loads of between 1.4 - 1.5% of the total characteristic dead load.

E.g. BS5628: Part 1 8 Clause 20.1 and 22 Notional Horizontal Load = 0.015 x Dead Load

BS5950: Part 1 7 Clause 4.2.3 Notional Horizontal Load = 1% of Factored Dead Load = 0.14 x Dead Load (typically)

In both these cases the notional loads are considered as design loads and should be compared with factored wind loads and design carried out for the worst case.

The 1.5% value represents 1 in 67 out of plumb (see Fig 5) which is equivalent to 74 - 236mm for the 2 to 8 storey range and seems more reasonable as a nominal allowance than the 2.5% figures quoted in 3.2.1.

BS5628 Clause 28.2.1 also addresses the problem of lateral restraint to walls and states that the elements providing this should be capable of transmitting to the elements of construction that provide lateral stability to the structure as a whole, the sum of the following design lateral forces:

(a) The simple static reactions to the total applied design horizontal forces at the line of lateral support, and

(b) 2.5% of the total design vertical load that the wall is designed to carry at the line of lateral support.

It then goes on to qualify (b) by saying that the elements of structure that supply stability to the structure as a whole need not be designed to support this force.

Designing strictly to BS5628 would, therefore, not only allow the adoption of a more reasonable value for lack of verticality but would also only require this force to be compared with the factored load and design carried out for the greater. It would also provide for restraint against buckling without the requirement to assume that all the restraint forces are acting simultaneously on the stabilising structure. BS5628, however, is a code of practice essentially geared towards new masonry buildings and it is too simplistic to apply it literally to the unusual case of an existing, usually quite high, free-standing wall being retained while major construction works are carried out in the immediate vicinity. In particular the following criticisms can be made of this approach when applied to such structures:

1. The 1.5% value is too low, and should be added to, rather than compared with, the factored wind load.

2. This method is intended for use with permanent, highly redundant structures where underestimation of loads can be readily absorbed by internal redistribution. Facade retention systems, however, are usually either statically determinate or first order redundant frameworks where the margin for error is small. Underestimation of loads on these vulnerable structures, which are exposed to the possibility of accidental impact, carries a much higher risk.

In answer to these criticisms the following arguments and suggested design approach are put forward:

1. The adoption of 1.5% as a nominal value seems quite reasonable for a nominally vertical wall (see Fig 5). If this is not the case the plumb survey would quickly reveal a problem and a more onerous figure would be used. If there are any eccentric features (such as on stonework facades) that do not individually warrant dead shoring, it may be necessary to increase that percentage by an appropriate amount to allow for these effects.

The argument that this notional load should be added, rather than compared, to the wind load would appear to be valid. It is the intention of the code to place a minimum value on the horizontal load for which a building should be designed. While the 1.5% load provides a reasonable lower limit for a complete building, of considerable mass, it will not provide a good comparison for a retained facade which may have similar wind loads but only a fraction of the mass. When the wind blows on such a wall its effect will be in addition to any out of plumb effects and the two must be considered as acting simultaneously.

2. It is true that the typical facade retention system is much less redundant structurally than a complete building and is therefore less forgiving if things go wrong. Designing for excessive out of plumb (as represented by 2.5% loads) may go some way towards covering the extra risk involved but it is not the best way of addressing the problem.

It is more important to carefully consider the robustness of the structure in terms of any likely accidental damage and to design the system to avoid collapse disproportionate to the cause. This will involve paying careful attention to members in vulnerable areas and either protecting them or designing them for accidental impact loads - see section 3.4.
3.2.3 Recommendations

In summary, therefore, it is recommended that, providing the plumb survey reveals nothing untoward, the notional horizontal load should be taken as 1.5% of the total dead load. This should be distributed amongst the walings in proportion to their spacing and combined unfactored with the design wind load. It should be noted that these 1.5% forces should include the self weight of the retention system itself to allow for any sway forces induced by erection tolerances etc.

Each individual waling should also be able to sustain the design wind loads plus 2.5% of the total design wall load above waling level to provide adequate lateral restraint against buckling. The system proper need only be designed for one waling load acting at any time.

3.3 Lateral Loads on Retaining Elements

Where buildings have one or more basement level, the section of the facade wall, below external ground level, will be subjected to horizontal forces due to pressure from retained material and any surcharge present. These walls will typically be propped, both in the existing and proposed permanent conditions, by ground and basement floors and also possibly by buttressing walls. In the period between demolition and completion of the new permanent bracing elements these propping forces will have to be provided temporarily either by incorporating additional props into the facade retention framework, or, by providing an independent shoring system specifically for this purpose. To properly estimate the loads for which these props must be designed it is necessary to carefully consider the extent of horizontal movement that can be tolerated without causing unacceptable damage to the wall.

BS5975 - The Falsework Code - Clause 28.5 gives guidance on the estimation of the earth pressure exerted by cohesive, cohesionless and mixed soils. It includes, however, the caveat that "calculated pressures will only be mobilised where equivalent strains occur" and that "these will be dependent on the elastic modulus of the soil and of the structural element as interacting members". It goes on to say that the restraining effect of struts etc. may give rise to greater pressures than those calculated using the basic active condition formulae. Section 5.6 of Foundation Design and Construction by Tomlinson discusses this in greater detail and suggests that a movement of 1/1000 - 1/500 of the retained height is necessary to mobilise active pressures. This horizontal movement of the wall will be accompanied by a corresponding movement in the retained soil and by settlement of the ground surface above.

These movements may not be acceptable and the propping system may have to be designed to avoid this. The lateral forces exerted on such a system will be greater than those associated with active conditions and should be calculated using the coefficient of earth pressure at rest which Tomlinson quotes as varying between 0.4 - 1.0 for loose sand and over consolidated clay respectively.

In providing foundations to resist the prop forces it should also be remembered that the full passive resistance of the soil is not mobilised without a much greater horizontal movement than that required for active conditions. Tomlinson provides further information and quotes movement of the order of 5% and 0.5% of the depth of embedment required to mobilise half the ultimate passive resistance of loose sands and dense sands respectively.

In summary, therefore, it is important that the allowable horizontal movement is considered when estimating lateral forces on retaining element. If it is required that these movements are severely restricted a very rigid shoring system will have to be installed. These props will be subject to pressures approaching those of earth at rest which will be higher than the active pressures generally designed for. It is important that the performance specification confronts these problems and clearly specifies the design criteria to be used.

3.4 Accidental Loads

As previously discussed, facade retention systems are usually either statically determinate or first order redundant structures in which damage or removal of any element may have serious consequences for overall stability. It should be emphasised that a successful facade retention scheme is one that is adaptable and can tolerate the abuse it will normally get during demolition and construction works. The robustness of these structures should, therefore, be carefully considered and the consequences of accidental damage assessed. This will involve an appraisal of the structure and its environment to identify areas of potential risk and consideration of how damage or removal of members in these areas would affect the structural performance. It is always preferable to prevent, rather than design for, accidental damage and, if possible, measures should be taken to protect these vulnerable areas. If this cannot be done some allowance will have to be made in the design to provide for the possibility of accidental impact loads.

Where external systems are used the outer legs of the framework will usually be particularly exposed to damage from vehicle impact. If ground level knowledge is used this may automatically provide adequate protection. If this is not the case some form of vehicle barrier should always be provided to reduce the risk. Heavy timber sleepers are often used to cordon of the area and while these offer some protection there will still be a risk, albeit reduced, of impact. The structural members in these areas, therefore, are usually designed for a nominal point load of 25kN applied anywhere on the member to allow for accidental impact.

Internal systems are mainly at risk from construction activities with perimeter members of the system being particular vulnerable to impact from heavy plant such as crane skips, piling rigs etc. Protection of these elements can be practically afforded by maintaining good organisation and supervision throughout the site and in particular in their immediate vicinity.

Inevitably, however, accidents will happen, and again a nominal allowance of 25kN impact load is generally made in design.

When designing these structures for impact loads the reduced risk of these occurring simultaneously with the design wind load should be recognised. Recommendations are given regarding this in Section 3.6.
3.5 Vertical Loads

In some cases a facade retention system will be required to provide vertical as well as lateral support to the wall. Secondary vertical props, for example, may need to be incorporated into the system to provide temporary support for individual overhanging facade features when the restraint provided by the existing structure is removed. On a larger scale, the lower framed section of the system may require to straddle the wall with the horizontal framing beams used as needles to support the wall above while work is carried out below (see Fig 2).

There may also be vertical loads as a consequence of any secondary use to which the system is put. In particular the following loads should be considered in addition to self weight.

1. Loads due to hutting, site offices etc. built into the system.

2. Loads due to placing kentledge at high level.

3. Loads due to use as an access scaffolding for work on the elevation. Table 1 of BS 5973 gives guidelines on what should be assumed in this case (see Fig 6).

It must be remembered, however, that when considering stability (see Section 3.6.1, case 1) the minimum dead load must be used which will usually only include the self weight of the system framework.

3.6 Design of Retention Systems for Ultimate Limit State (BS 5950: Part 1)

Custom built steel facade retention systems are typically constructed of hot rolled sections designed to BS 5950: part 1. Clause 2.4 of this code discusses the various ultimate limit states, such as strength, stability, fatigue, brittle fracture and structural integrity, that should be considered when designing any steel structure. In the particular case of a facade retention system only stability, strength and integrity will usually be relevant and these are discussed further, with suggested load factors and combinations given, in sections 3.6.1 - 3.6.3 that follow.

3.6.1 Stability Limit State

The code requires that a two-fold check be carried out to ensure that the overall structure has adequate resistance to overturning and sway. Resistance to overturning is mainly a foundation problem and will be covered later in Section 3.8. Sway stability requires that the overall structure is sufficiently strong to resist the horizontal forces, in addition to any vertical loads, factored and combined as follows:

1. A horizontal load = 1.4x(W + E) + .015 D_W + R acting with a vertical load = 1.0 D_R

2. A horizontal load = 1.2 x (W + E) + .015 D_W + R acting with A vertical load = 1.2 D_R + 1.2I

Where:

W = Wind Load
E = Earth Pressure Load (if present)
D_W = Dead Load of Wall
D_R = Dead Load of Retention System
I = Imposed Load on Retention System

Each individual waling should also be
checked for a horizontal load $= 1.4 \left( W + E \right) + 0.025 \times \text{dead load of wall above waling level}$. The overall structure need only be capable of resisting the load from any one of these walings acting alone.

It should be remembered that all the above horizontal design loads, with the exception of earth pressure, are reversible and that checks should be carried out in both directions. The loads given are those appropriate to a stability check perpendicular to the wall. A similar exercise should be carried out in the longitudinal direction where both wind and notional horizontal loads will be less.

### 3.6.2 Limit State of Strength

The vertical load carrying capacity of the structure should be verified by checking for the combination of $1.4D_w$ and $1.6I$. This check will not usually be critical for design as horizontal load effects are usually dominant.

### 3.6.3 Structural Integrity

Section 3.4 discusses the robustness of these structures and recommends additional impact loads for design. When designing for these accidental loads it is unreasonable to assume that these occur simultaneously with the maximum values of other, more ordinary loads.

BS 5950 recognises this fact and clause 2.4.5.5 recommends that these accidental loads are combined with the dead load plus one third of the imposed and wind loads. A load factor of 1.05 should be used on all loads except when considering resistance to overturning where beneficial dead load should be multiplied by 0.9 and imposed load ignored or included as appropriate for the worst case.

### 3.7 Design of Retention System for Serviceability Limit State (BS 5950: Part 1)

Clause 2.5 of BS 5950 discusses the two serviceability limit states of deflection and durability. The latter is not usually considered important for temporary structures, such as facade retention systems, where painting of the steelwork may be purely a local authority requirement imposed for aesthetic reasons. Deflection, however, is a very important consideration and will often, in fact, govern the design.

An assessment of the facade needs to be undertaken by the Consultant to determine the deflection limit considered appropriate. The design forces should be combined as follows for the deflection check:

A horizontal load $= 1.0 \left( W + E \right) + 0.015 D_w , a$ acting with

A vertical load $= 1.0 D_a + 1.0 I$

Where loads are as defined in Section 3.6.1.

If a large vertical imposed load is present (such as kentledge at an upper level) it may also be necessary to consider this placed asymmetrically on the frame to assess any secondary sway effects.

The deflection calculation will be based on an elastic analysis of the structure which does not allow for any cumulative effects due to bolt slippage at connections. To ensure this does not cause problems the framework should, as much as possible, be prefabricated in large sections with site bolted joints reduced to a minimum and additional site welding of bolted connections carried out.

### 3.8 Foundation Design

The foundation for a facade retention system is primarily required to provide resistance, with an adequate factor of safety, to overturning and sliding. In Section 3.6.1, Case 1 defines the ultimate limit state for which the overturning effects will be maximised and suggests that a factor of 1.4 is acceptable. This, however, is based on BS 5950 and is intended for checking how structural steel, a highly predictable material, will perform.

When considering the kentledge provided by a concrete foundation the slightly more onerous safety factor of 1.5 is used to allow for the less consistent nature of the material. In checking sliding a factor of 2.0 is considered appropriate to allow for the uncertainty involved in the estimation of passive pressures, if these are assumed to be mobilised, and of $\mu$ = the coefficient of friction (suggested values are given in table 18 of BS 5975 - see Fig 61).

Foundations will also have to be sized to give acceptable bearing pressures but while this is not usually critical it is important to keep bearing pressures low as differential settlement of the legs will be magnified many times over at the top of the system.

### 3.9 Temporary Connection to Retained Facade

The connections between the temporary frame and the facade must take into account the relative fragility of the stone and masonry present. Ideally the walls should be attached over as large an area as possible as, although the individual fixings may be strong enough, the integrity of the base material is usually less certain. It is for this reason that clamping systems are usually used. These generally consist of steel walings clamped on either side of the facade using long tie bolts the pressure being spread by timber packers to protect the facade surface as shown in Figure 7.

Theoretically, the walings should be placed at floor levels. These zones, however, may not be readily accessible and connection in these areas will usually be troublesome requiring through drilling and destructive
breaking out. Window openings, therefore, if strong enough, are usually preferred as restraint points. These also have the advantage that they are usually far enough away from the new floor levels to avoid clashing with permanent fixings.

3.10 Permanent Connection to New Structure

The connections between the old facade and new permanent structure must provide the wall with the required lateral restraint to wind, out of plumb and buckling forces while, at the same time, allow for relative vertical movement between old and new construction.

This movement can arise due to settlement of the new structure relative to the existing wall which may, in fact, move upwards due to heave effects caused by relaxation of loading.

3.10.1 Connection To The Facade

The variable and often unknown nature of masonry dictates that selection of the fixings is verified by tests, installation is carried out by trained operatives under supervision, and that post installation checks are carried out. Where proprietary fixings are used manufacturers advice should be sought and carefully followed. Explicit instructions covering installation proceed, including drill size, depth, tightening torque etc. should be given and, as already mentioned, preliminary tests carried out to verify pull out loads. The variable nature of masonry makes it advisable to design the fixings on a redundant basis and multiple fixing points should always be used.

Of the proprietary fixings available resin anchors are most often used because of their good performance in base materials of poor quality. Pumped resin will generally be preferred to encapsulated systems as this copes better with the variable nature of the material. Where resin anchors are used the overall fire resistance of the fixing system will have to be carefully considered and fire protection applied as necessary.

3.10.2 Provision for Movement

Generally the connection to the facade should be made as late as the construction programme will permit so that as much settlement as possible can take place prior to fixing.

For through bolted systems (Fig 8) relative vertical movement is usually allowed by the flexibility of the tie rod moving in an oversized hole through the facade. Where drilled proprietary fixings are used vertical slots and PTFE washers provide movement. The connections can be made at floor level, to either the floor structure itself or its supporting beams (Fig 9), or at any level to the columns.

3.11 Use of Proprietary, Component Systems

In many cases it will be possible to build up the facade retention system using off the shelf, hireable components, rather than steelwork specifically fabricated for the job in hand. The systems available range from the traditional scaffold tube / ladder beam framework suitable for low rise facades to the more substantial "soldier" system originally developed for use with modular vertical shuttering systems. These soldiers are typically composed of two cold formed channels, spaced back to back, and welded together. The overall weight of the unit is typically reduced by cutting holes in the web at constant intervals along its length. The edge of this hole is usually shaped to offset the strength loss due to the perforations.

The decision to use such a system will be based on consideration of the following advantages and disadvantages.

Advantages

1. On contracts of short duration it will be possible to hire out the components, thereby reducing cost. Generally, however, if they are required for periods in excess of one year it will be more economic to purchase the components and sell them back when the contract is completed.

2. There is a minimal lead in time involved as the components are generally stock items. This is particularly important as demolition and retention of the facade are usually foremost on the critical path for the project.

3. Crange can be kept to a minimum as most of the components can be manhandled and pre-assembly is facilitated.
Disadvantages

1. There is a limited range of components compared to the choice of hot rolled steel sections available. This will lead to over design of the members towards the top of the frame and over complication in the lower sections of tall systems where doubling up, or increased system width, maybe necessary.

2. The system is not generally suited to the vertical tower scheme outlined in 2.4.3. While there may be a possibility of using proprietary formwork girders as stiff horizontal walings the concentration of load vertically, in the tower members, usually places them outside the range of most proprietary systems.

3. The standard joint between members has a limited moment capacity making framing between ground and first floor (for through access) difficult. This can be overcome by introducing knee braces into the frame. It may, however sometimes be necessary to adopt a more straightforward solution using a purpose built steel portal frame between ground and first floor with the proprietary system used above that level.

When these considerations have been taken into account the cost / benefit of using a proprietary system can be evaluated. If chosen the detail design will usually be done by the suppliers / manufacturers to comply with the performance specification. Components will generally be chosen on a permissible load basis, in accordance with research carried out by the manufacturer, and then checked for deflection limits. This will usually represent a minimum factor of safety of between 1.7 - 1.8 on ultimate failure.

SUMMARY

In summary, this paper recommends that the design of any facade retention system is approached as a two stage process, firstly involving the production of a performance specification, by the design team, for inclusion in the tender documents, followed by the detailed design of the system by the contractor.

The performance specification should aim to give all information relevant to the design of the system as well as specifying it's required performance in service. The final scheme choice and detail design is left to the Contractor as this makes for a more "user friendly" design that minimises buildability problems.

There is no British Standard available that is specifically concerned with the detailed design of these systems. The wind loads may be assessed by using CP3 - the wind code, and it's handbook, along with relevant sections of the falsework and scaffolding codes. It is recommended that when using CP3 a value of $S_3 = 1.0$ is used for the deflection check instead of the more traditional value of $S_3 = 0.77$. This will ensure that the risk of the design wind speed being exceeded is reduced to a level more appropriate to this type of structure. The traditional allowance of 2.5% of the dead load for lack of verticality would seem to be excessive and modern codes of practice suggest a lower value of 1.5% along with an individual waling check for 2.5% of the total dead load above waling level. Modern Codes also require that the robustness of the structure be considered and this is particularly important for facade retention systems which usually have little, if any, structural redundancy and where failure could have very serious consequences. Potentially vulnerable areas should be identified and protected or alternatively the members in these areas should be designed for accidental impact loads. It is suggested that careful consideration of robustness is amore effective way of minimising risk than over design for loads due to excessive lack of verticality. Careful attention should also be paid to elements of the facade below ground level, where earth pressure due to retained material will be largely dependent on the allowable horizontal movement.

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References