
Ezra Mac Manamon
Engineering Services
Office of Public Works
Presentation to
Heritage Society of
the Institution of Engineers of Ireland
22 November 2004
From my case studies, I’ll be talking to you about -

- **Lime** - Manufacture, properties, and the different types of lime.
- **Water** - Some of its adverse effects on Building structures, and their durability.
- **Bonding in Stone Masonry**. - Through Stones, Bond Stones and Bonding between courses.
- **Design Philosophy for Masonry ties** - What are they expected to do?
- **The need for Appraisal of Buildings prior to carrying out refurbishment.**
- **Safety Issues**- examples of issues that arose in cases.
LIME

Manufacture, Properties, Types
• The Lime Cycle -

Limestone $\text{CaCO}_3$

- Burn in Kiln $\sim 900^\circ\text{C}$
- $\text{CO}_2 >$

- Quicklime $\text{CaO}$

- Addition Of Water $\text{H}_2\text{O}$ - Slaking

- Slaked Lime $\text{Ca(OH)}_2$

- Carbonation $\text{CO}_2$ absorbed from air, $\text{H}_2\text{O}$ given off

Safety Note
Lime - Points to Note

• Setting process in lime described so far is by reaction with Carbon Dioxide, from the air.

• This means that Lime mortars can not set under water. They are ‘Air’ Limes, or ‘Fat’ Limes. They are not Hydraulic.

• There are other limes which are able to set under water which are known as Hydraulic Limes or Naturally Hydraulic Limes.
Lime - Points to Note - cont’d

• There is a harmonized European Standard, IS EN 459 2001, which deals with the various types of building limes.

• Limes designated as Hydraulic Limes can in fact be non-Hydraulic but with additional materials such as Pozzolanic materials (Catalysts) or White Cement added to give a Hydraulic set.
Lime

• Depending on the type of Lime, and the construction, Lime may not actually set deep within a wall. Historic walls dismantled, and soft mortar discovered in Core.

• In use, all limes must be protected from drying out to quickly, and from frost until they have gained strength. (anal. curing concrete)
Lime

• Historically, limes used would have varied, Non Hydraulic, Hydraulic, or with some additives, such as sea shells or burnt clay.

• This variation was in part due to variety in qualities or properties of raw materials, such as Dublin Calp Limestone, or Limestone in Shannon Basin, and in part to the presence of impurities, whether added or naturally occurring. (Historical awareness of hydraulicity???)

• Much about Lime that we don’t know --
WATER

Some of its undesirable effects on Building Structures.
Effects of Water Ingress - Masonry

- rubble fill in ‘cavity’ bound with intact mortar.

- Examples of disintegrated mortar & fill materials -

- Mortar often removed from joints

- Freeze thaw actions, de-lamination of renders

- Face construction on each side (btw)
Effects of Water Ingress - Timber

- Allows wood attacking fungi, > Dry & Wet Rot
- Increased mc allows attack by insects which wouldn’t attack drier wood
Effects of Water Ingress -

• Water causes or promotes deterioration of materials (Timber, Mortar, Plaster, Metals) in buildings if not kept out.

• Keeping water out is a fundamental requirement in the maintenance and conservation of buildings.
BONDING IN STONE MASONRY
Definitions. (Patrick Mc Afee - Irish Stone Walls).

- **Bond** - The arrangement of stones in a wall to give structural stability and to control the placement of vertical joints.
Definitions. (Patrick Mc Afee - Irish Stone Walls).

Through Stone - A stone which extends from one face of the wall to the other thereby holding both faces together.

Bond Stone - A stone which travels a considerable distance from one face of a wall to the other. In normal work they are at least two thirds of the width of the wall.
Tullaherin Round Tower,
Thought to date from 11th Century
View of Tower in 1999.
Some increase in bulge in lower third in tower, comparison with earlier photos.
Also increase in cracking in the masonry.
Why has this deterioration happened?
Can be seen that core filling material has become loose.
Carefully cut masonry (in elevation)
Inward and outward pressure arising from disintegration and loosening of rubble fill.

Spreading (Tension) forces in outer skin as a result of pressure from loosened rubble fill.

Compressive forces in inner skin resulting from pressure from loosened rubble fill.

Joint width uniform

Inward and outward pressure arising from disintegration and loosening of Rubble fill.

Illustration of initial system of forces arising from disintegration and loosening of rubble core fill.

Magnitude of pressure from core filling?

Resistance of Tension forces in outer skin - friction between courses.

If stones cut as drawn, and stones in alternate courses staggered, then masonry should be able to resist such forces.

However -
More realistic estimation of shapes of stones in a typical course of masonry.

Joints increase in width towards core because stones cut with 'splayed' ends.

Core filling.

Consider potential for resistance of tension forces in outer skin now.

Drawing showing one courses of masonry. Outline only of individual stones drawn. Variation in stone size not shown.
Two Courses of masonry - Area of overlapping stones useful for resistance of tension forces hatched.

*How do we estimate shape of stones?*

Area available for resistance of tensile forces in outer skin shown thus. (i.e. overlapping areas)

No Overlap in this area

Stone in lower course shown thus (Red).

Overlapping area hatched thus.

Minimal Overlap

Stone in upper course shown thus (Blue).

Drawing showing Two courses of masonry, one overlying the other. Outline only of individual stones drawn. Resistance of forces is by friction between the courses, in the outer skin.
View of Entrance into Tower.

- Inspection through opened vertical joints.
- Bonding at some cracks
- Original masonry forming doorway stolen a long time ago.
- Stones forming the side of the opening probably representative of typical masonry in tower.
- Next slide is a view -
View looking up side of tower, at doorway.

Note shape of stones -
No bond stones visible in sectional views of wall at doorway.
• Crack over doorway, as in picture.
• - extended upwards some distance,
• Note repair area at and below door. (keep in mind for later)
• Recall the system of forces - Tension in outer face & Comp. in inner face.
• Looking inside the Door
• Crack over doorway, on inside face also.
• Contradicts system of forces?
• Tower is leaning towards SW, opposite side to Door.

• Most Bulging of wall at SW side, in lower third.

• Looked at levels of joints around tower – Up to 300mm variation Over Door.

• Was crack related to movement of tower, or deterioration of masonry on opposite side?

• Replicate effect with Computer model?

• Considered the use of a simple physical model.
• Two Models.
• Approximately proportional to tower in diameter & thickness.
• Door openings added.
• One model had a series of cuts to ‘model’ deterioration on side opposite doorway.
• Both models cut over door to allow material to open, if there was a tendency to do so, ‘under load’.
• Model which included ‘deterioration’ (cuts) showed a clear tendency to open over the doorway when light loading was applied.

• Concluded that crack over doorway was a secondary effect which followed on from deterioration of the tower on the opposite (SW) side.
In a Circular masonry wall, pressure from disintegrated core filling leads to

- Tension forces in outer skin
- Resisted by friction between courses.
- If no overlap between courses > No strength > cracks develop.
- Lack of proper bonding between courses, on same face.
- In a straight wall, additional effect occurs as follows-
Pressure from loose disintegrated core filling material causes:

- Settlement of filling material
- Pressure on faces of wall
- Bulging of faces of wall, if no through stones or bond stones in wall.
- This has occurred in Tullaherin Round Tower, as well as cracking from spreading forces in outer skin.
- This effect can also occur in a retaining wall with Ashlar facing masonry, as in next case -
Grand Canal, 9th Lock, Clondalkin, Dublin.

• View along South wall of upper lock chamber.

• Note bulge in wall

• This part of Grand canal constructed in mid 18th Century, about 1760 to 1780 or so.

• This part of the canal was the first part of the canal to be constructed
Drawing showing profile of lock Chamber.

- Extent of separation of ashlar facing from backing masonry.
- Considered possible causes-
  - Stability of wall
  - Separation of ashlar from backing
  - Hydrostatic pressure

Section 1–1 (Scale Approximately 1:50)
Typical section of lock showing maximum extent of bulge in facing masonry on south wall.
Buried surface of wall exposed by excavation -

- Determined geometry of wall
- Thus could check stability by calculation
- Wall stable when complete, but -
- If ashlar removed, wall could overturn into lock chamber.
- This information used in risk assessment with regard to repair works.
Extracts from Specification for Royal Canal Extension to Shannon, prepared by John Killally, Engineer, in 1814.

- Attention to bond stones to tie ashlar to backing masonry
- JK worked on Grand Canal completion in 1806.
- Many of first lock chambers failed as recorded in minute book -

THE side walls, extending from 29Ft. 8In. above the upper cove, to 32Ft. below the lower cove, are to be built of ashlars, laid in courses, from 8 to 21In. in height, with bonds of corresponding heights, and not more than 5Ft. asunder. — The bonds to be at least, 12In. long on the face, and 3Ft. deep in the bed. — The stretchers to have 12In. bed at least, and in no case less bed than height.

The top and bottom beds, and also the upright joints of the ashlars and bonds, to be punched for 9In. square to the face, and the arrases to be chisel-dressed — the remainder of the bed to be fair hammer-dressed.

The face of the stones to be punched fair out of winding, with a chisel draft, round the arrases, and in the setting, care must be taken to break joints, 6In. at least, and that the stones are laid on their natural bed, and at right angles to the face, excepting the cove stones.
In the meantime Captain Tarrant’s reports confirmed the board’s worst fears. In April he reported that the dam in the level above the Morrell lock had given way and at the 6th lock ‘the ashlaring on the North side of the Chamber to an extent of 30ft and from Top to Bottom of the Central Part, sprung out like a long bow.’ A week later he wrote: ‘On Wednesday the 9th April the Lock East of the Morrell Lock having been thrice filled – that day the Ashlaring of the South Wall of the Chamber burst from an unconnected body of rubble which appears as open spaces between the stones. I found the North and South Walls of the Chamber bulged and lower wing wall overhanging – after the first filling the Water being discharged there was a muddy water at the foot of the Walls and a Discharge of the same thro’ joints a bad omen of its condition.’
Repairs works to be carried out

- No Bonding between ashlar and backing
- Water in gap which opened between ashlar and backing
- Hydrostatic pressure pushed ashlar out.

• Minimal Intervention Principle - comment
Detail of Tie as inserted during reconstruction -

- Ties based on Hilti HY 50 system.
- Capacity estimated by engineer at design stage.
- At start of works capacity of anchor verified by site testing.

- Ashlar Being replaced.
- Props to stabilise wall
- Note shape of some of the stones (similar to Tullaherin)
Views of repaired lock chamber
What are masonry ties intended to do, exactly? Or what loads are they intended to resist?

If loading is clearly hydrostatic, as in the case of the water between the ashlar and the backing masonry, then loading on proposed ties is clear.

This leads to an arrangement of tie spacing as shown below.
If on the other hand, the loading is from disintegrated, loosened core filling material, is the loading -

• Hydrostatic, as in a soil mechanics model of say, At Rest Pressure? or

• Local to discrete ties as inserted (Cavity wall tie type spacing)?

• Temporary, until the wall is grouted, (and thus the loose material is replaced with solid material, after being washed out)?

• These are alternative possibilities.
Suggestions with regard to loading on masonry wall ties.

• If loading is from water, then loading is clear.

• If loading is from disintegrated loosened core filling material, then the loading probably depends on the nature of the material.

• If generally fine (relatively) material, then loading probably near hydrostatic - spacing as in Lock repair.

• If material consists of large fragments or large stones which are not bound, then loading is probably nearer being local to discrete wall ties as installed.

• If the loose material is to be replaced by washing out and grouting, then are ties just there to hold the wall together while the washing out and grouting is going on?
A 17\textsuperscript{th} Century Church Tower, in the midlands.

This is the South elevation of the tower, summer 1999.

The whole southern half of the tower has collapsed, (the south wall, and half of each of the east and west walls).

Note bulge in left face of the east wall.

Note timber lintels over the visible openings at low level.

No Bond or through stones visible in wall sections exposed.

If it’s here today……..
View of entrance doorway to tower.

Note arch profile

Note right part of upper arch collapsed

Note timber lintel behind,

Note poor condition of masonry.
Views of east wall

Notes
Crack on both faces
Arch
Lintel
What Happened?

• Short relieving arches, combined with shrinkage or rotting of lintels.

• Spreading forces from arches, as arches settled following lintels.

• As well as the effects of weather and water ingress (No Evidence of a roof on the tower in recent times).
Recommendations/ Options Considered.

- Considered that tower was in very dangerous condition, and that vibrations or minor impacts could trigger further collapses.

- **Take no action and await further collapses**

- **Demolish upstanding remains possibly with a view to rebuilding.**
  - *Install temporary shoring to protect upstanding remains of tower.*
  - *Repair upstanding remains and possibly rebuild collapsed portion*

- **Safety of potential workers and members of the public most important.**

- National Monuments passed on my report to ‘owner’ but said demolition option was not to be implemented.

- A couple of years later, a second opinion was sought by the ‘owner’/local authority.
The Second Opinion

• Structure deteriorated as a result of arch thrusts, and some differential settlement.
• Cracking caused tower to become a number of discrete units, rather than one integral unit.
• Possible to tie upstanding remains together and render them an integral stable unit.
• Proposals -
Sketch Proposals West Wall

- Phase I & II works nearly completed.
- Phase III remaining, (grouting & Replacement of Lintels)
- Quite scary at times during works.
- Confidence built up in structure as work progressed.
Two Opinions

• Engineers can be very close technically, but come down on different sides of a line in making decisions

• “To dangerous to work on, until some maintenance work carried out”

• Duty under H&S legislation for Designers to carry out Risk assessments.
APPRAISAL OF BUILDINGS

The need to do so before refurbishment.
Appraisal of Buildings.

- Publication by I.Struct.E., “Appraisal of Existing Structures”
- Article in “Construction Repair” 1994
- Case studies refer to conventional building refurbishment projects, as well as historic or protected structures.
Building 1
Refurbishment Specification Summary.

• Specification submitted in support of application for grant assistance.
• Exterior - Repoint and re-render walls
  - Replace damaged downpipes
  - Replace drainage channel with new one to ‘keep water out from wall’
• Interior - Replacement of Ground Floor slab on DPM
  - Some re-plastering and re-pointing as well as some dry lining.
Specification adequate basis for Grant Assistance??

• My approach was to carry out an inspection of the building, and carry out a Structural Appraisal.

• One of the issues referred to in the specification was the replacement of down pipes.

• On initial inspection of the exterior, I noticed one location where a down pipe was blocked and broken, at about first floor level.
Inspection inside the building at this location
Inspection in other parts of the building

Typical of Joist ends in Large Floor (at external wall).

Joist ends in Landing in Party Wall
Repeated attempts at Notching.
Joists 34mm x 280mm, - Notches up to 50mm deep.
Located at Midspan.
Seriously weakened Floor
Building 1 - Conclusion

• Advised that more professional advice be obtained and that thorough structural appraisal be completed in order to fully identify necessary works.
• Consideration to be given to intended use.
• Imagine if refurbishment proceeded on basis of specification submitted, with client on very tight budget??
Building 2.

- Large open ended hay-shed type structure.
- Protected structure.
- Building to be refurbished, and early client decision to replace roof finish and structure.
- Structure made up of light wrought iron trusses.
- No signs of structural distress, some deterioration.
- Consultants report advised trusses inadequate for loads required by modern codes, in particular wind loading.
Building 2

• Suggestions that lack of straightness in bottom chord was due to buckling, arising from wind uplift loading.

• Perception by some that engineers report was an attempt to justify clients early decision to replace roof.

• There was no proposal to alter the use of, or maintenance regime for the roof which would have led to a change in loading on the structure.
Building 2

- I expressed the view that the structure was probably adequate structurally based on the history and age of the building, and that some repairs may be necessary. Replacement of the structure was probably not necessary in my opinion.
- The structure warranted a full structural appraisal, with the preservation and repair of the structure as the primary option to be given serious consideration.
- I felt that this was particularly appropriate because this was part of a significant protected structure, and also because the roof structure was the work of a historically significant engineer.
Building 2

- Difficulties for consulting engineers in this situation, as other professionals, in giving truly independent advice or opinion.
- Also difficulty for consulting engineers in terms of professional indemnity and certification of their work.
To Sum Up ---

- Lime – There are different types of lime, both Historically, and at present. Refer to EN 459. If you are using lime, protect it.
- Water – Keep it out of your buildings!
- Remedial Ties – Consider required ‘design’ loading.
- Be conscious of bonding in stone masonry
- Appraisal of buildings before refurbishment. Need I say …… Engineering Heritage…..
- Thank You.