



# Eurocode 6 Study

For  
DOEHLG  
And  
ICF

FINAL REPORT

COMPARATIVE  
DESIGN STUDIES

(updated)  
January 2010

This report and its comparative designs were prepared to inform preparation of the Irish National Annex to IS EN 1996. They must not be relied upon in substitution for specific designs for other purposes.

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***January 2010 revision – table at foot of page 28 amended, columns 3 & 5***

## **1. BACKGROUND**

Lee McCullough were commissioned by the Department of the Environment, Heritage and Local Government to carry out an independent study on Eurocode 6 - which covers the Design of Masonry Structures. This study was jointly funded by the Department of the Environment, Heritage and Local Government and the Irish Concrete Federation.

The study objectives were:

- To evaluate the technical implications for structural design in Ireland, arising from Eurocode 6.
- To produce draft National Annexes for each part of that code.

The first phase of the study required a number of comparative structural designs to be prepared with a view to proposing Irish NDP's for the Irish National Annex.

The second phase required the production of National Annexes, and the review of the current Building Regulations to highlight any implications for the existing Technical Guidance Documents A and B which may arise from the introduction of EN 1996.

This final report follows presentations to the client steering group, feed back over a period of time, and further guidance received in respect of block, mortar and masonry properties appropriate for use in the calculations.

## **2. NATIONALLY DETERMINED PARAMETERS (NDP'S)**

The Eurocode programme recognises the responsibility of regulatory authorities in each Member State and has safeguarded their right to determine values related to regulatory safety matters at a national level where these continue to vary from State to State. As such, a number of parameters within the Eurocodes are left open for national choice. These are known as Nationally Determined Parameters (NDPs) and their values are contained in a National Annex. Values (or ranges of values) for these particular parameters are "recommended" in EC6, but left open for national determination.

## **3. WALLS EXAMINED**

We prepared designs for five specific wall situations as set out in the RFT, i.e.:

- Two storey domestic houses
- Freestanding walls
- Industrial panel walls
- External walls of typical offices ("Spandrel" walls)
- Six storey apartments

As agreed with the sub-group, we took examples of walls from previously designed buildings, slightly simplified to make them relevant as more general examples of their type.

The objective was to compare design outcomes from the Eurocode with values obtained from the current Irish and British Standards to give an indication of the Eurocode impact on structural wall design in Ireland.

#### **4. DESIGN CODES USED**

The Request for Tender (RFT) stated:, “*The study shall undertake comparative designs of a range of typical masonry building structures, using current Irish and British Standards and Eurocode 6 (EC 6).*” Accordingly, we prepared designs for the various wall elements to the following codes:

- IS 325: Incorporating the 1996 amendments to the original 1986 code.  
BS 5628: As updated in 2005.  
EC6 (Rec): Using the “recommended” values for Nationally Determined Parameters (NDP’S).  
EC6 (UK): Using the NDP’s from the UK National Annex (UK NA).

Following feedback on our earlier reports from the Masonry sub-group, we added the comparison with the values that we proposed for the EN 1996 National Annex:

- EC6 (IS): Using the NDP’s selected in our proposed Irish National Annex (IS NA).

#### **5. LOADS USED**

The loads for use in the design were calculated by reference to BS 6399 Parts 1 and 2 for the IS325 and BS5628 codes; and to EN 1991-1-1 and BS 6399 Part 2 for the Eurocodes designs. The National Annex for EN 1991-1-4 covering wind loads has yet to be issued so we were instructed to use BS 6399 - 2 as a suitable alternative.

To select appropriate wind loads, we referred to the Building Regulations map of Ireland setting out three zones (A, B, C). For each zone we took a town approximately in the middle of the zone and calculated the wind load there using BS 6399. (*Zone A – Maynooth, Zone B – Clonmel, Zone C – Westport*).

#### **6. WALL DIMENSIONS**

The wall panel dimensions, wall thicknesses, and the loads used are set out in the tabulated results.

#### **7. BLOCK STRENGTHS**

- 7.1 As part of the original study briefing given to us, the Request for Tender (RFT) document, at Appendix 10, noted:

***“Concrete Masonry Units specified to IS EN 771-3: 2003 and tested to IS EN 772-1: 2000***

- 1. Historically concrete blocks tested to IS 20 - Part 1: 1987 allowed for blocks up to and including 10N to be tested using soft board capping method. IS EN 772-1:2000 / IS 771-2: 2005 requires the preparation of concrete blocks for strength testing to be ground or mortar capped. Concrete blocks mortar capped before testing show higher strength values than IS 20 methods.*

*Approximate correlation between blocks tested to I.S. 20 as compared to blocks tested to IS EN 772-1 will be agreed with the masonry panel to facilitate an initial design to EC 6.*

2. The IS EN 771-2: 2003 allows either the mean strength or the characteristic compressive strength. The strengths of concrete blocks supplied in Ireland are mean strength.
3. For the comparative design exercise a **Category II unit** can be assumed and Group 1 and Group 2 units.
4. IS EN 771-3, Clause 5.5.1.1. allows “whole units or parts of units may be tested in an orientation other than the orientation of the normal use of the units provided there is adequate correlation between the direction of testing and of use. Under IS 20, usage of concrete blocks on flat 450 x 100 x 215 were:
- (a) Tested on the edge.
  - (b) For blocks with an edge strength of less than 10 N/mm<sup>2</sup> an equivalent flat strength of 1.6 x edge test result can be assumed.
  - (c) For blocks with an edge strength greater than 10 N/mm<sup>2</sup> an equivalent flat strength of 1.2 x edge test result plus 4.0 N/mm<sup>2</sup> can be assumed.
- For the use of blocks on the flat in the comparative designs, the above criteria can still be assumed.”

**7.2** IS 20 stipulates the blocks be soaked in water and wet when tested, IS EN 772 allows for blocks to be air dry or wet at testing time, which affects the test result – the same blocks fail at a higher load when dry than when soaked wet.

At the beginning of Phase 1 we received a table, based on tests from a variety of Irish block manufacturers, which indicated the differences between the same blocks tested to IS 20 and IS EN 772-1. The table produced values that were the mean strength equivalent to the IS 325 units, to be used in the Eurocode calculations. The values were:

IS 20		IS EN 772-1
5N Solid Unit	=	6.5 N Equivalent Strength
10N Solid Unit	=	13 N Equivalent Strength
20N Solid Unit	=	26 N Equivalent Strength
3N Hollow Unit	=	4 N Equivalent Strength
5N Hollow Unit	=	6 N Equivalent Strength

**7.3** Following earlier calculation reports, guidance was received to the effect that **Category 1 blocks were to be assumed for all calculations, with “Execution Class 5 taken as equivalent to the IS 325 “Normal” category of construction control, and Class 4 as equivalent to “Special” category.**

(Block “**Category**” refers to standard of production control; “**Execution Class**” refers to standards of construction workmanship.)

**7.4** The word “**masonry**” in the context of structural design codes is taken as meaning a wall built of units e.g. blocks or bricks.

The design Codes IS 325 and BS 5628:2005 tabulate:

- The compressive strength of masonry (i.e. a wall) by reference to the compressive strength of the units (i.e. of the blocks in this case) used to construct it.

- The flexural strength of masonry by reference to the mortar grade and the compressive strength of the units.

For both of these codes the compressive strength of the masonry units is defined as the “**mean**” strength, i.e. the average strength of the stipulated number of blocks tested. IS 325 uses IS 20 as the test method reference, while BS 5628:2005 uses EN 772-1 as a test reference.

- 7.5** EN 1996 references the “**normalised**” compressive strength of the units (i.e. blocks) in its formula for masonry compressive strength.

For flexural strength of masonry EN 1996 “Recommended” takes account only of the mortar grade, whereas the UK National Annex also takes account of the “declared compressive strength” of the units.

We were initially unsure as to whether this “declared compressive strength” is the “mean” strength or the “normalised mean” or the characteristic (3.1.2 of EN 1996 refers). By comparing the similarities between UK NA *Table NA6* and *Table 3* in BS 5628:2005 we concluded that it should be the “mean” strength.

- 7.6** “**Normalised**” compressive strength is defined as “*the air dried compressive strength of an equivalent 100mm wide x 100mm high masonry unit*”.

The “Informative” Annex A in EN 772-1 proposes a method of deriving “Normalised” block strengths from “mean” block strength.

It tabulates factors to allow conversion of “mean” to “normalised” strengths, taking account of whether the blocks were tested, for example, in air dry or wet condition, and whether the blocks were tested on edge or on flat.

Following Annex A logic for blocks on edge:

5N blocks per IS 20 are given as 6.5N per EN 772 in our RFT guidance. We then multiply 6.5 by 1.2, to convert to air dry condition, and by 1.35, the shape factor acknowledging the tests were done on edge, and get 10.5N Normalised strength.

Therefore, for blocks on edge, i.e. 100mm wide:

$$5\text{N (mean strength per IS 20)} = 6.5\text{N (mean strength per EN 772)} = 10.5\text{N "normalised" (EN 772)}$$

Following Annex A logic for blocks on flat:

5N unit from IS 20, 6.5N in EN 772, multiplied by the edge to flat conversion factor, given in RFT Appendix 10, 1.6, results in a strength of 10.4N on flat. Then correcting to normalised strength – multiplying by 1.2, to convert to air dry condition, and by 0.8, the shape factor acknowledging the tests were done on flat, we get 10N Normalised strength.

So for blocks on flat, i.e. 215mm wide:

$$5\text{N (IS 20 mean) on edge} = 6.5\text{N (EN 772 mean on edge)} = 10.4\text{N (EN 772 mean on flat)} = 10\text{N "normalised" (EN 772)}$$

## 7.7 Conclusion Regarding Block Strengths for Design Purposes

The equivalent strengths for the same blocks loaded on edge under the design codes bracketed are:

5N Unit Strength	(IS325),
6.5N mean	(BS5628:2005),
10.5N normalised	(EN1996 Recommended),
10.5N normalised	(EN1996, UKNA)

In similar fashion to the equivalences for the 5N blocks, and based also on supplied information we derived equivalent figures for the 10N and 20N “IS 20” blocks under the various codes, we calculated EN 772 equivalents for the 30N blocks by extrapolating the relationships indicated in the study information.

The equivalent strengths used in the block on flat calculations for this report are as follows:

EC6 (Rec)	EC6 (UK)	BS 5628	IS 325
Strength based on EN 772	Strength based on EN 772	Strength based on EN 772	Strength based on IS 20
10 N/mm <sup>2</sup> normalised	10 N/mm <sup>2</sup> normalised	6.5 N/mm <sup>2</sup> Mean	5N Unit
20 N/mm <sup>2</sup> normalised	20 N/mm <sup>2</sup> normalised	13 N/mm <sup>2</sup> Mean	10 N Unit
34 N/mm <sup>2</sup> normalised	34 N/mm <sup>2</sup> normalised	26 N/mm <sup>2</sup> Mean	20 N Unit
49 N/mm <sup>2</sup> normalised	49 N/mm <sup>2</sup> normalised	39 N/mm <sup>2</sup> Mean	30 N Unit

## 8. MORTAR STRENGTHS

Appendix 10 in the RFT indicated that we should use a set of mortar strengths taken from *IS EN 845-1: 2003 Specification for Ancillary Components for Masonry*. These strengths were M1 for (iv) mortar, M2.5 for (iii), M5 for (ii), and M10 for (i) mortar.

Following discussions with the masonry sub group after our earlier reports we were asked to modify these values to M2 for (iv) mortar, M4 for (iii), M6 for (ii), and M12 for (i) mortar. These changes resulted in the compressive strength of the masonry made with the designated grade (iii) mortar being increasing for the Eurocode designs by comparison with designs for the same blocks and mortar under IS 325 and BS 5628.

## 9. UTILISATION FACTORS

The comparative figures, given below in our calculations, are “Utilisation Factors”. A utilisation factor is the ratio obtained when the applied load is divided by the load capacity of the wall in question, and will differ for each code used.

A utilisation factor of 1 means that the applied load is equal to the design load capacity of the wall. A factor greater than 1 indicates the load is in excess of the wall design capacity. A factor less than 1 (e.g. 0.4) means that the load is within the theoretical

wall capacity (in this example the applied load would be 0.4 times the wall design capacity, or 40% of its capacity).

Consequently a utilisation factor of 1 or less indicates a satisfactory design, whereas a factor greater than 1 indicates the wall is theoretically overstressed or unstable.

## **10. LATERALLY LOADED WALL PANELS**

Our calculations show that using the “recommended” NDP values in EC6 produces very significantly more conservative designs than IS 325.

Following consideration of interim reports, the Masonry Sub Group issued guidance (as mentioned in 7.3 above) that IS 325 values for the critical parameter – characteristic flexural strength of masonry, which is related to block and mortar strengths, should be incorporated in this study.

Hence we have recalculated the laterally loaded wall panels and tabulated the results under the column heading EC6 (IS)

# CALCULATIONS, RESULTS, COMMENTS

## 1. TWO STOREY HOUSE WALLS (VERTICAL LOAD)

	EC6 (Rec / IS)	EC6 (UK)	BS 5628	IS 325
<b>Block Strength</b>	10.5 N/mm <sup>2</sup> normalised	10.5 N/mm <sup>2</sup> normalised	6.5 N/mm <sup>2</sup> Mean	5N Unit
<b>Mortar</b>	M4	M4	M4	(iii)
$\gamma_m$	2.7	2.7	3.1	3.1
$\gamma_g$	1.35	1.35	1.4	1.4
$\gamma_q$	1.5	1.5	1.6	1.6

The Utilisation ratios for the external cavity wall in a two storey house under vertical pressure are given below:

<b>100mm EXTERNAL CAVITY WALL (VERTICAL LOAD)</b>				
<i>Ground Floor 100/100/100 Cavity Wall, 2.6m High</i>				
EC6 (Rec)	EC6 (UK)	BS 5628	EC6 (IS)	IS 325
0.32	0.32	0.32	0.32	0.43

<b>100mm INTERNAL WALL (VERTICAL LOAD)</b>				
<i>Ground Floor 100mm Wall, 2.6m High</i>				
EC6 (Rec)	EC6 (UK)	BS 5628	EC6 (IS)	IS 325
0.18	0.18	0.27	0.18	0.34

### COMMENTS

Green shading indicates the wall is within its load capacity, in this case all the walls are within capacity.

The Eurocode 6 utilisation factors are lower (more advantageous) than the same wall construction judged by IS 325 analysis.

## 2. TWO STOREY HOUSE WALLS (LATERAL LOAD)

	<b>EC6 (Rec / IS)</b>	<b>EC6 (UK)</b>	<b>BS 5628</b>	<b>IS 325</b>
<b>Block Strength</b>	6.5 N/mm <sup>2</sup> Mean	6.5 N/mm <sup>2</sup> Mean	6.5 N/mm <sup>2</sup> Mean	5N Unit
<b>Mortar</b>	M4	M4	M4	(iii)
$\gamma_m$	2.7	2.7	3.0	3.1
$\gamma_g$	1.0 / 1.35	1.0 / 1.35	1.0 / 1.4	1.0 / 1.4
$\gamma_q$	1.5	1.5	1.4	1.4

In the EN code cases the  $\gamma_f$  load factor on wind (dictated in EN 1990) is 1.5 - it is treated the same as any other "variable" load. BS and Irish codes use  $\gamma_f$  of 1.4 for wind where failure of a wall panel would affect stability of the remaining structure.

The wind loading obtained from BS 6399 – 2 was:

<b>Wind Loading</b>	
<b>Zone A</b>	0.80 kN/m <sup>2</sup>
<b>Zone B</b>	1.00 kN/m <sup>2</sup>
<b>Zone C</b>	1.10 kN/m <sup>2</sup>

The Utilisation ratios for the external cavity wall under lateral pressure in a two storey house are given below:

<b>100mm EXTERNAL CAVITY WALL (LATERAL LOAD)</b>					
<i>First Floor 100/100/100 Cavity Wall, 3.115m Long &amp; 2.5m High</i>					
	<b>EC6 (Rec)</b>	<b>EC6 (UK)</b>	<b>BS 5628</b>	<b>EC6 (IS)</b>	<b>IS 325</b>
<b>Zone A</b>	1.13	0.42	0.43	0.45	0.47
<b>Zone B</b>	1.41	0.52	0.54	0.57	0.59
<b>Zone C</b>	1.55	0.58	0.60	0.62	0.64

<b>100mm EXTERNAL CAVITY WALL (LATERAL LOAD)</b>					
<i>Ground Floor 100/100/100 Cavity Wall, 6.1m Long &amp; 2.6m High</i>					
	<b>EC6 (Rec)</b>	<b>EC6 (UK)</b>	<b>BS 5628</b>	<b>EC6 (IS)</b>	<b>IS 325</b>
<b>Zone A</b>	1.45	0.58	0.66	0.58	0.62
<b>Zone B</b>	1.81	0.73	0.83	0.73	0.78
<b>Zone C</b>	2.00	0.80	0.91	0.80	0.86

We then considered these walls with standard 5N hollow blocks in place of the traditional 100mm internal loadbearing blocks. The Utilisation ratios for the external cavity wall with hollow blocks under lateral pressure in a two storey house are given below:

<b>HOLLOW BLOCK (Group 2) EXTERNAL CAVITY WALL (LATERAL LOAD)</b>					
<i>First Floor 215/100/100 Cavity Wall, 3.115m Long &amp; 2.5m High</i>					
	<b>EC6 (Rec)</b>	<b>EC6 (UK)</b>	<b>BS 5628</b>	<b>EC6 (IS)</b>	<b>IS 325</b>
<b>Zone A</b>	0.61	0.31	0.32	0.22	0.23
<b>Zone B</b>	0.76	0.39	0.40	0.27	0.29
<b>Zone C</b>	0.84	0.43	0.44	0.30	0.32

<b>HOLLOW BLOCK (Group 2) EXTERNAL CAVITY WALL (LATERAL LOAD)</b>					
<i>Ground Floor 215/100/100 Cavity Wall, 6.1m Long &amp; 2.6m High</i>					
	<b>EC6 (Rec)</b>	<b>EC6 (UK)</b>	<b>BS 5628</b>	<b>EC6 (IS)</b>	<b>IS 325</b>
<b>Zone A</b>	0.84	0.50	0.52	0.45	0.48
<b>Zone B</b>	1.05	0.63	0.65	0.56	0.60
<b>Zone C</b>	1.15	0.69	0.72	0.62	0.66

We also considered these walls with 5N hollow blocks, rendered outer leaf & dry-lined internally, in place of the traditional cavity wall. The Utilisation ratios are given below:

<b>HOLLOW BLOCK (Group 2) EXTERNAL WALL (LATERAL LOAD)</b>					
<i>First Floor 215 Wall, 3.115m Long &amp; 2.5m High</i>					
	<b>EC6 (Rec)</b>	<b>EC6 (UK)</b>	<b>BS 5628</b>	<b>EC6 (IS)</b>	<b>IS 325</b>
<b>Zone A</b>	0.74	0.36	0.39	0.26	0.28
<b>Zone B</b>	0.92	0.47	0.49	0.33	0.35
<b>Zone C</b>	1.01	0.52	0.54	0.36	0.39

<b>HOLLOW BLOCK (Group 2) EXTERNAL WALL (LATERAL LOAD)</b>					
<i>Ground Floor 215 Wall, 6.1m Long &amp; 2.6m High</i>					
	<b>EC6 (Rec)</b>	<b>EC6 (UK)</b>	<b>BS 5628</b>	<b>EC6 (IS)</b>	<b>IS 325</b>
<b>Zone A</b>	1.02	0.61	0.63	0.55	0.59
<b>Zone B</b>	1.27	0.76	0.79	0.68	0.73
<b>Zone C</b>	1.40	0.84	0.87	0.75	0.81

## **COMMENTS**

*The pass (green highlighted) or fail (red highlighted) walls are consistent between the codes.*

*However the EC6 (Rec) designs all fail, because of the low “Recommended” values for characteristic flexural strength ( $f_{yk}$ ) in EN 1996. The higher  $\gamma_q$  factor in EC6 design also contributes to the difference.*

*Using our proposed  $f_{yk}$  figures for Eurocode 6 (figures taken from IS 325), the calculated EC6 (IS) and IS 325 utilisation factors are very close.*

### 3. TWO STOREY HOUSE WALLS (CONCENTRATED LOAD)

	<b>EC6 (Rec / IS)</b>	<b>EC6 (UK)</b>	<b>BS 5628</b>	<b>IS 325</b>
<b>Block Strength</b>	10.5 N/mm <sup>2</sup> normalised	10.5 N/mm <sup>2</sup> normalised	6.5 N/mm <sup>2</sup> Mean	5N Unit
<b>Mortar</b>	M4	M4	M4	(iii)
$\gamma_m$	2.7	2.7	3.1	3.1
$\gamma_g$	1.35	1.35	1.4	1.4
$\gamma_q$	1.5	1.5	1.6	1.6

We studied a steel beam loaded by a timber first floor and resting on a masonry wall – variously a 100mm leaf, a 215 leaf and a 215 leaf with a concrete pad under the beam.

The Utilisation ratios for the internal wall under a concentrated load in a two storey house are given below:

<b>INTERNAL WALL (CONCENTRATED LOAD)</b>					
<i>Ground Floor 100mm Wall, 2.6m High</i>					
	<b>EC6 (Rec)</b>	<b>EC6 (UK)</b>	<b>BS 5628</b>	<b>EC6 (IS)</b>	<b>IS 325</b>
<b>100mm</b>	0.97	0.97	0.82	0.97	0.96
<b>215mm</b>	0.50	0.55	0.64	0.50	0.67
<b>215 w Pad</b>	0.16	0.17	0.29	0.16	0.30

## **COMMENTS**

*All design cases pass in the situation examined.*

*The EC6 (IS) and IS 325 results are practically identical for the 100mm block on edge case. For the 215mm block on flat cases EC6 (IS) design gives lower (more advantageous) utilisation factors than the IS 325 design.*

#### 4. CHIMNEYS

	<b>EC6 (Rec / IS)</b>	<b>EC6 (UK)</b>	<b>BS 5628</b>	<b>IS 325</b>
<b>Block Strength</b>	6.5 N/mm <sup>2</sup> Mean	6.5 N/mm <sup>2</sup> Mean	6.5 N/mm <sup>2</sup> Mean	5N Unit
<b>Mortar</b>	M4	M4	M4	(iii)
$\gamma_m$	2.7	2.7	3.0	3.1
$\gamma_g$	1.0	1.0	1.0	1.0
$\gamma_q$	1.5	1.5	1.4	1.4

To compare like with like we examined chimneys projecting 1.3m above roof level, constructed with blocks laid on edge, and also with blocks laid on flat. The wind loading obtained from BS 6399-2 was:

<b>Wind Loading</b>	
<b>Zone A</b>	0.92 kN/m <sup>2</sup>
<b>Zone B</b>	1.15 kN/m <sup>2</sup>
<b>Zone C</b>	1.27 kN/m <sup>2</sup>

The Utilisation ratios for the chimneys are given below:

<b>100mm CHIMNEY (LATERAL LOAD)</b>					
<i>450mm square, 100mm Wall, 1.3m High</i>					
	<b>EC6 (Rec)</b>	<b>EC6 (UK)</b>	<b>BS 5628</b>	<b>EC6 (IS)</b>	<b>IS 325</b>
<b>Zone A</b>	2.07	0.41	0.43	0.41	0.44
<b>Zone B</b>	2.59	0.52	0.54	0.52	0.55
<b>Zone C</b>	2.84	0.57	0.59	0.57	0.61

<b>215mm CHIMNEY (LATERAL LOAD)</b>					
<i>675mm square, 215mm Wall, 1.3m High</i>					
	<b>EC6 (Rec)</b>	<b>EC6 (UK)</b>	<b>BS 5628</b>	<b>EC6 (IS)</b>	<b>IS 325</b>
<b>Zone A</b>	0.85	0.24	0.25	0.17	0.18
<b>Zone B</b>	1.06	0.31	0.32	0.21	0.23
<b>Zone C</b>	1.17	0.34	0.35	0.23	0.25

## **COMMENTS**

*The pass (green highlighted) or fail (red highlighted) walls are consistent between the codes.*

*However the EC6 (Rec) designs all fail, because of the low “Recommended” values for characteristic flexural strength ( $f_{yk}$ ) in EN 1996. The higher  $\gamma_f$  factor also contributes to the difference.*

*Using our proposed  $f_{yk}$  figures for Eurocode 6 (figures taken from IS325), EC6 (IS) and IS 325 utilisation factors are very close.*

## 5. FREESTANDING WALLS

	<b>EC6 (Rec / IS)</b>	<b>EC6 (UK)</b>	<b>BS 5628</b>	<b>IS 325</b>
<b>Block Strength</b>	6.5 N/mm <sup>2</sup> Mean	6.5 N/mm <sup>2</sup> Mean	6.5 N/mm <sup>2</sup> Mean	5N Unit
<b>Mortar</b>	M4	M4	M4	(iii)
$\gamma_m$	2.7	2.7	3.0	3.1
$\gamma_g$	1.0	1.0	1.0	1.0
$\gamma_q$	1.5	1.5	1.2	1.2

In the EN code cases the  $\gamma_f$  load factor on wind is 1.5; BS and Irish codes use 1.2 in this free standing wall situation (where failure of the wall panel does not endanger stability of the remaining structure).

We studied a plain 215mm thick wall, and a 215 wall with 675 deep x 450 wide piers symmetrically disposed about the 215 wall. The wind loading obtained from BS 6399 – 2 was:

<b>Wind Loading</b>	
<b>Zone A</b>	0.70 kN/m <sup>2</sup>
<b>Zone B</b>	0.86 kN/m <sup>2</sup>
<b>Zone C</b>	0.95 kN/m <sup>2</sup>

The Utilisation ratios for the freestanding walls are given below:

<b>215mm FREESTANDING WALL (LATERAL LOAD)</b>					
<i>215mm Wall, 1.8m High</i>					
	<b>EC6 (Rec)</b>	<b>EC6 (UK)</b>	<b>BS 5628</b>	<b>EC6 (IS)</b>	<b>IS 325</b>
<b>Zone A</b>	3.53	2.04	1.83	1.62	1.41
<b>Zone B</b>	4.34	2.51	2.25	1.99	1.73
<b>Zone C</b>	4.81	2.78	2.49	2.20	1.91

<b>215mm FREESTANDING WALL PERMITTED HEIGHT</b>					
	<b>EC6 (Rec)</b>	<b>EC6 (UK)</b>	<b>BS 5628</b>	<b>EC6 (IS)</b>	<b>IS 325</b>
<b>Zone A</b>	0.96m	1.26m	1.33m	1.42m	1.52m
<b>Zone B</b>	0.86m	1.14m	1.20m	1.28m	1.37m
<b>Zone C</b>	0.82m	1.08m	1.14m	1.21m	1.30m

<b>215mm FREESTANDING WALL W/ PIERS (LATERAL LOAD)</b>					
<i>215mm Wall with 450*675 Deep Piers at 2.7m c/c, 1.8m High</i>					
	<b>EC6 (Rec)</b>	<b>EC6 (UK)</b>	<b>BS 5628</b>	<b>EC6 (IS)</b>	<b>IS 325</b>
<b>Zone A</b>	2.04	1.19	1.06	0.94	0.82
<b>Zone B</b>	2.51	1.45	1.30	1.15	1.00
<b>Zone C</b>	2.78	1.61	1.44	1.27	1.11

<b>215mm FREESTANDING W/ PIERS PERMITTED HEIGHT</b>					
<i>215mm Wall with 450*675 Deep Piers at 2.7m c/c, 1.8m High</i>					
	<b>EC6 (Rec)</b>	<b>EC6 (UK)</b>	<b>BS 5628</b>	<b>EC6 (IS)</b>	<b>IS 325</b>
<b>Zone A</b>	1.26m	1.65m	1.75m	1.86m	1.99m
<b>Zone B</b>	1.14m	1.49m	1.58m	1.68m	1.80m
<b>Zone C</b>	1.08m	1.42m	1.50m	1.59m	1.71m

Taking into consideration the feedback from the Masonry Sub Group we analysed two more common type of freestanding walls used in Ireland. The Utilisation ratios for the freestanding walls are given below:

<b>215mm FREESTANDING WALL (LATERAL LOAD)</b>					
<i>215mm Wall, 1.2m High</i>					
	<b>EC6 (Rec)</b>	<b>EC6 (UK)</b>	<b>BS 5628</b>	<b>EC6 (IS)</b>	<b>IS 325</b>
<b>Zone A</b>	1.57	0.91	0.82	0.72	0.63
<b>Zone B</b>	1.93	1.12	1.00	0.88	0.77
<b>Zone C</b>	2.14	1.24	1.11	0.98	0.85

<b>215mm FREESTANDING WALL W/ PIERS (LATERAL LOAD)</b>					
<i>215mm Wall with 450*675 Deep Piers at 2.25m c/c, 1.8m High</i>					
	<b>EC6 (Rec)</b>	<b>EC6 (UK)</b>	<b>BS 5628</b>	<b>EC6 (IS)</b>	<b>IS 325</b>
<b>Zone A</b>	1.56	0.92	0.82	0.73	0.63
<b>Zone B</b>	1.95	1.13	1.00	0.89	0.78
<b>Zone C</b>	2.17	1.25	1.11	0.99	0.86

## **COMMENTS**

*In each case the EN 1996 "Recommended" NDP calculation basis indicates utilisation factors significantly higher (less advantageous) than IS 325.*

*This is because of the low "Recommended" values for characteristic flexural strength ( $f_{yk}$ ) in EN 1996. The higher  $\gamma_f$  load factor by comparison with IS 325 (1.5 versus 1.2) also contributes to the difference.*

*The failures that occur in these walls are pier failures rather than panel failures.*

*Using our proposed  $f_{yk}$  figures for Eurocode 6 (figures taken from IS 325), EC6 (IS) and IS 325 utilisation factors are close but EC6 (IS) is less advantageous for design in this case mainly because of the  $\gamma_q$  load factor values (1.5 versus 1.2).*

## 6. OFFICE SPANDREL WALLS

In this example, we analysed an external spandrel wall, 1m high under a 2m high window, under wind load.

	<b>EC6 (Rec / IS)</b>	<b>EC6 (UK)</b>	<b>BS 5628</b>	<b>IS 325</b>
<b>Block Strength</b>	6.5 N/mm <sup>2</sup> Mean	6.5 N/mm <sup>2</sup> Mean	6.5 N/mm <sup>2</sup> Mean	5N Unit
<b>Mortar</b>	M4	M4	M4	(iii)
$\gamma_m$	2.7	2.7	3.0	3.1
$\gamma_g$	1.0	1.0	1.0	1.0
$\gamma_q$	1.5	1.5	1.4	1.4

The wind loading obtained from BS 6399-2 was:

<b>Wind Loading</b>	
<b>Zone A</b>	0.75 kN/m <sup>2</sup>
<b>Zone B</b>	0.90 kN/m <sup>2</sup>
<b>Zone C</b>	1.00 kN/m <sup>2</sup>

The Utilisation ratios for the office spandrel walls are given below:

<b>215mm CAVITY SPANDREL WALL (LATERAL LOAD)</b>					
<i>215/100/100 Cavity Wall, 1m High &amp; Posts at 2.4m c/c</i>					
	<b>EC6 (Rec)</b>	<b>EC6 (UK)</b>	<b>BS 5628</b>	<b>EC6 (IS)</b>	<b>IS 325</b>
<b>Zone A</b>	0.61	0.28	0.30	0.20	0.19
<b>Zone B</b>	0.73	0.34	0.36	0.24	0.23
<b>Zone C</b>	0.81	0.38	0.40	0.26	0.26

<b>215mm SPANDREL WALL (LATERAL LOAD)</b>					
<i>215 Wall, 1m High &amp; Posts at 2.4m c/c</i>					
	<b>EC6 (Rec)</b>	<b>EC6 (UK)</b>	<b>BS 5628</b>	<b>EC6 (IS)</b>	<b>IS 325</b>
<b>Zone A</b>	0.74	0.34	0.37	0.24	0.23
<b>Zone B</b>	0.88	0.41	0.44	0.29	0.28
<b>Zone C</b>	0.98	0.46	0.49	0.32	0.31

## **COMMENTS**

*Recent computer software for masonry wall analysis (CADS “Masonry Wall Panel Designer Max”) sets out a method for analysing panels such as these spandrel walls with their upper / free edge subject to lateral load from a window. We have followed that method in hand calculating moments for the EC6 analysis.*

*While the panel analysis “passes” under all design codes, the EC6 (Rec) utilisation factors are very much higher (less advantageous) than those for IS 325.*

*This is again because of the low “Recommended” values for characteristic flexural strength ( $f_{xk}$ ) in EN 1996. The higher slightly  $\gamma_f$  load factor by comparison with IS 325 (1.5 versus 1.4) also contributes to the difference.*

*Using our proposed  $f_{xk}$  figures for Eurocode 6 (figures taken from IS 325), EC6 (IS) and IS 325 utilisation factors are close.*

## 7. INDUSTRIAL PANEL WALLS

In this example, we analysed an industrial panel wall, 5m high and 7m wide, supported on all four sides, under wind load.

	<b>EC6 (Rec / IS)</b>	<b>EC6 (UK)</b>	<b>BS 5628</b>	<b>IS 325</b>
<b>Block Strength</b>	6.5 N/mm <sup>2</sup> Mean	6.5 N/mm <sup>2</sup> Mean	6.5 N/mm <sup>2</sup> Mean	5N Unit
<b>Mortar</b>	M4	M4	M4	(iii)
$\gamma_m$	2.7	2.7	3.0	3.1
$\gamma_g$	1.0	1.0	1.0	1.0
$\gamma_q$	1.5	1.5	1.2	1.2

The wind loading obtained from BS 6399 – 2 was:

<b>Wind Loading</b>	
<b>Zone A</b>	0.75 kN/m <sup>2</sup>
<b>Zone B</b>	0.90 kN/m <sup>2</sup>
<b>Zone C</b>	1.00 kN/m <sup>2</sup>

The Utilisation ratios for the industrial panel walls are given below:

<b>215mm CAVITY INDUSTRIAL WALL (LATERAL LOAD)</b>					
<i>215/100/100 Cavity Wall, 5m High &amp; 7m Wide</i>					
	<b>EC6 (Rec)</b>	<b>EC6 (UK)</b>	<b>BS 5628</b>	<b>EC6 (IS)</b>	<b>IS 325</b>
<b>Zone A</b>	1.34	0.74	0.66	0.44	0.47
<b>Zone B</b>	1.62	0.89	0.79	0.53	0.57
<b>Zone C</b>	1.80	0.99	0.88	0.59	0.63

<b>215mm INDUSTRIAL WALL (LATERAL LOAD)</b>					
<i>215 Wall, 5m High &amp; 7m Wide</i>					
	<b>EC6 (Rec)</b>	<b>EC6 (UK)</b>	<b>BS 5628</b>	<b>EC6 (IS)</b>	<b>IS 325</b>
<b>Zone A</b>	1.63	0.90	0.81	0.53	0.57
<b>Zone B</b>	1.97	1.08	0.97	0.64	0.69
<b>Zone C</b>	2.19	1.20	1.08	0.71	0.77

We then considered these walls with standard 5N hollow blocks in place of the traditional 215mm internal loadbearing blocks. The Utilisation ratios for the industrial walls with hollow blocks under lateral pressure are given below:

<b>HOLLOW BLOCK (Group 2) CAVITY INDUSTRIAL WALL (LATERAL LOAD)</b>					
<i>215/100/100 Cavity Wall, 5m High &amp; 7m Wide</i>					
	<b>EC6 (Rec)</b>	<b>EC6 (UK)</b>	<b>BS 5628</b>	<b>EC6 (IS)</b>	<b>IS 325</b>
<b>Zone A</b>	1.55	1.01	0.90	0.84	0.77
<b>Zone B</b>	1.87	1.22	1.08	1.00	0.93
<b>Zone C</b>	2.08	1.35	1.20	1.12	1.03

<b>HOLLOW BLOCK (Group 2) INDUSTRIAL WALL (LATERAL LOAD)</b>					
<i>215 Wall, 5m High &amp; 7m Wide</i>					
	<b>EC6 (Rec)</b>	<b>EC6 (UK)</b>	<b>BS 5628</b>	<b>EC6 (IS)</b>	<b>IS 325</b>
<b>Zone A</b>	1.88	1.23	1.09	1.00	0.94
<b>Zone B</b>	2.27	1.48	1.32	1.23	1.13
<b>Zone C</b>	2.52	1.64	1.46	1.37	1.25

## **COMMENTS**

*Because bending again governs the outcome, EN 1996 "Recommended" is much less advantageous than IS 325.*

*This is because of the low "Recommended" values for characteristic flexural strength ( $f_{yk}$ ) in EN 1996. The higher  $\gamma_f$  load factor by comparison with IS 325 (1.5 versus 1.2) also contributes to the difference.*

*Using our proposed  $f_{yk}$  figures for Eurocode 6 (figures taken from IS325), EC6 (IS) and IS 325 utilisation factors are close.*

## 8. APARTMENT BUILDING WALLS

We examined two wall cases:

- An external cavity wall 215/100/100, (carrying half of a 7.6m floor span) where the outer leaf load is transferred to the inner leaf by a relieving angle at third floor level.
- A 215mm internal corridor wall, (carrying half of a 7.6m span slab from one side, and half of a 1.8m span on the other)..

The floors were taken as concrete topping on precast prestressed concrete wide slab units (250mm overall depth) spanning from external to internal walls.

### MASONRY UNIT AND MORTAR QUALITY PROPERTIES AS USED IN THIS SECTION

<b>Block Reference</b>	<b>EC6 (Rec/IS)</b>	<b>EC6 (UK)</b>	<b>BS 5628</b>	<b>IS 325</b>
	<b>Strength based on EN 772</b>	<b>Strength based on EN 772</b>	<b>Strength based on EN 772</b>	<b>Strength based on IS 20</b>
<b>(5N)</b>	10 N/mm <sup>2</sup> normalised	10 N/mm <sup>2</sup> normalised	6.5 N/mm <sup>2</sup> Mean	5N Unit
<b>(10N)</b>	20 N/mm <sup>2</sup> normalised	20 N/mm <sup>2</sup> normalised	13 N/mm <sup>2</sup> Mean	10 N Unit
<b>(20N)</b>	34 N/mm <sup>2</sup> normalised	34 N/mm <sup>2</sup> normalised	26 N/mm <sup>2</sup> Mean	20 N Unit
<b>(30N)</b>	49 N/mm <sup>2</sup> normalised	49 N/mm <sup>2</sup> normalised	39 N/mm <sup>2</sup> Mean	30 N Unit
<b>Mortar</b>	M4	M4	M4	(iii)
$\gamma_m$	2.7	2.7	3.1	3.1
$\gamma_g$	1.35	1.35	1.4	1.4
$\gamma_q$	1.5	1.5	1.6	1.6

The strengths and relationships for 5, 10, and, 20 N/mm<sup>2</sup> blocks (IS 20) converting to EN 772 were taken directly from information provided for this study. We calculated EN 772 equivalents for 30N blocks by extrapolating the relationships indicated in the study information.

Case 1 was the external cavity wall. The Utilisation ratios for these walls are given below:

<b>EXTERNAL APARTMENT WALL (VERTICAL LOAD)</b>					
<i>215/100/100 Cavity Wall, 3m High</i>					
	<b>EC6 (Rec)</b>	<b>EC6 (UK)</b>	<b>BS 5628</b>	<b>EC6 (IS)</b>	<b>IS 325</b>
<b>6th (5N)</b>	0.41	0.43	0.44	0.41	0.46
<b>5th (5N)</b>	0.78	0.84	0.80	0.78	0.83
<b>4th (10N)</b>	0.79	0.83	0.80	0.79	0.86
<b>3rd (20N)</b>	0.81	0.87	0.80	0.81	0.90
<b>2nd (30N)</b>	0.77	0.82	0.80	0.77	0.91
<b>1st (30N)</b>	0.87	0.95	0.95	0.87	1.09

Case 2 was the internal wall. The Utilisation ratios for these walls are given below:

<b>INTERNAL APARTMENT WALL (VERTICAL LOAD)</b>					
<i>215 Wall, 3m High</i>					
	<b>EC6 (Rec)</b>	<b>EC6 (UK)</b>	<b>BS 5628</b>	<b>EC6 (IS)</b>	<b>IS 325</b>
<b>6th (5N)</b>	0.19	0.21	0.36	0.19	0.36
<b>5th (5N)</b>	0.43	0.48	0.61	0.43	0.63
<b>4th (5N)</b>	0.66	0.73	0.87	0.66	0.91
<b>3rd (10N)</b>	0.56	0.61	0.74	0.56	0.81
<b>2nd (10N)</b>	0.71	0.77	0.94	0.71	1.02
<b>1st (10N)</b>	0.85	0.92	1.13	0.85	1.23

### **COMMENTS**

*In general, the EC6 utilisation factors are lower (more advantageous) than IS 325.*

*This is partly due to the lower load factors (1.35 and 1.5 versus 1.4 and 1.6)*

*However a greater influence in favour of EC6 is its method for determining eccentricity – and thus the Capacity Reduction Factor - on a loaded wall.*

## EN 1996 – SOME POINTS TO NOTE

### 1 TERMINOLOGY

The terminology use in EN 1996 (EC6) is quite different to that in IS 325, so for ease of reference we have included a glossary of some terms used in our report in the next section.

### 2 WALLS UNDER VERTICAL LOAD

In general we found EC6 to be less conservative in terms of compressive design of masonry walls than IS325.

The method of determining the eccentricity of loading on a wall is significantly different in EC6 by comparison with IS 325. In IS 325 the rules are somewhat arbitrary or “rule of thumb” whereas the EC6 method is more theoretical and apparently rational. As mentioned in our comments at the end of the apartment wall design section, the result is that EC6 indicates greater loads can be carried by the wall constructions investigated than IS 325.

### 3 WALLS UNDER LATERAL LOAD

EC6 using the “Recommended” values for the NDP’s  $f_{xk1}$  and  $f_{xk2}$  is significantly more conservative than IS 325, but this situation is redressed if (as we have proposed in the draft National Annex to EN 1996–1) the  $f_{kx}$  values from IS325 are used.

### 4 WIND LOAD PARTIAL FACTORS

The partial factor ( $\gamma_q$ ) for wind loads to be used in EC6 is set by EN 1990 at 1.5. By comparison IS 325 equivalents are 1.4 or 1.2 where the wall in question is not essential for the stability of a building.

### 5 BLOCK STRENGTHS

In our opinion it would be most helpful for designers if block and brick manufacturers were to quote the mean and the normalised compressive strength of the units they manufacture. There is also a philosophical question as to what different strengths should be produced: the old 5N, 10N, 20N blocks per IS20 equate to 6.5N, 13N, 26N per information supplied to us.

### 6 MORTAR SPECIFICATION, IS EN 998

Per EN 1996, “designed” masonry mortar should be classified by compressive strength (e.g. M4). We believe that more mortar cube testing will be required to be assured that the stipulated standard is achieved – as opposed to the situation heretofore where (for example) mortar grade (iii) based on mix proportions was not uncommonly used in load bearing masonry without a rigorous site strength checking procedure. However further specification requirements will be necessary since it appears that strength alone may not assure sufficient durability, and workability is likely to require additions to mixes which would satisfy strength. Hence “prescribed” mix description may be more appropriate in many cases (e.g. M4, 1:1:6). Judging from information supplied during our study, some rationalisation of Standard Mortar specifications in IS EN 998 should be considered if the M4 designation as the equivalent of the former grade (iii) is accepted, as EN 998 calls up M1, M2.5, M5, M10 etc.

### 7 NEED FOR NCCI

There is a significant volume of accumulated practical and detailing advice in IS325 which is not covered in EC6. We believe it would merit republishing as Non Contradictory Complementary Information (NCCI) specifically relevant to Irish practice and conditions of weather exposure. Such NCCI is proposed in at least one other jurisdiction. We suggest this should be raised at the next NEAC meeting.

## **8 ACCIDENTAL DAMAGE**

Accidental damage did not enter directly into the Comparative Design tasks we were set. Nevertheless that subject arises in the context of the Building Regulations and consequences arising from EC6, which is in our brief.

Accidental damage limitation requirements were clearly laid out in IS325, and are not as directly covered in EC6.

Section 5.2 of EN 1996 states “ In addition to designing the structure to support loads arising from normal use, it shall be ensured that there is a reasonable probability that it will be damaged under the effect of misuse or accident to an extent disproportionate to the cause”. It goes on to reference EN 1991–1–7 as the source of accidental actions (i.e. loads) to be used in such design cases.

IS EN 1991-1-7-Eurocode “Actions on Structures – Part 1-7 General Actions – Accidental Actions” provides strategies and rules for safeguarding buildings against accidental actions. It defines strategies based on limiting the extent of localised failure.

Annex A (Informative) of that document gives guidance on design for consequences of localised failure in buildings from an unspecified cause. The Irish National Annex IS EN 1991-1-7 confirms that this informative Annex may be used in Ireland.

The Annex together with Section 3 “Design Situations” of the main IS EN 1991-1-7 text gives an approach to the provision of sufficiently robust buildings based on the concept of “Consequence Classes” which relate to the type, size and use of buildings.

Examples of building categorisation are given in Annex A, and recommended strategies to achieve an acceptable level of robustness are also set out there.

Three alternative strategies are outlined for limiting the extent of localised failure, and “one or more” of the three is to be followed:

- Design key elements for the accidental load
- Design for local failure not to exceed the lesser of 15% of the floor area or 100m<sup>2</sup>, but maintain the overall building stability
- Apply prescriptive design / detailing rules (e.g. 3D tying...).

Approaches in respect of horizontal and vertical ties, notional removal of elements of structure, key element design and risk analyses are also described, and it is interesting to note parallels in principle to the IS 325 approach in these clauses. For example, in A.6 the requirement to have vertical ties in load bearing walls “at 5m centres along the wall” and “no greater than 2.5 m from an unrestrained end of the wall” is set out.

We recommend, in the context of EN 1996–1 that Annex A of EN 1991–1– 7 must be followed, i.e. for the purposes of EN 1996 masonry design that Annex A of EN 1991–1– 7 should be considered Normative.

## SOME EUROCODE TERMINOLOGY

<b>"Action"</b>	load or an imposed deformation (e.g. temperature effects or settlement)
<b>"Effects of Actions"</b> or <b>"Action effects"</b>	are internal moments and forces, bending moments, shear forces and deformations caused by actions
<b>"Execution"</b>	Covers all activities carried out for the physical completion of the work including procurement, the inspection and documentation thereof. The term covers work on site; it may also signify the fabrication of components off site and their subsequent erection on site.
<b>"Class of Execution Control"</b>	Essentially standard of site construction work in EC6 context
<b>Units</b>	Blocks, bricks, etc
<b>Unit "Category"</b>	Production standard,
<b>Category I</b>	Units with a probability of failure to reach declared compressive strength less than 5%;
<b>Category II</b>	Units not intended to comply with level of confidence of category I units (EN 771-3:2003)
<b>Unit "Group"</b>	A measure of the degree of solidity of the unit (e.g. block)
<b>"Group 1"</b>	Units essentially contain <25% voids;
<b>"Group 2"</b>	Voids lie between 25% and 60%
<b>Unit Strengths:</b>	
<b>"Mean" strength.</b>	The average strength of the stipulated number of blocks tested
<b>"Normalised" compressive strength</b>	"The air dried compressive strength of an equivalent 100mm wide x 100mm high masonry unit".
<b>Mortar designations</b>	The most important designation now is compressive strength, with the addition of prescribed proportions if specified e.g. M4, or M4 1:1:6.