Craig O'Neill

Concrete Crushing testing report

Real life laboratory

Craig O'Neill
5/9/2012

Introduction to concrete lab reports

This report is an insight to the current practices used today in concrete construction. It follows the processes involved in concrete design, concrete mixing, curing and testing.

The class exercise was to produce a series of concrete cubes to be tested 14 and 28 days after initial setting for their compressive strength. This is to highlight the change in concrete strength as time passes.

The second exercise involved the group mixing and forming a steel reinforced concrete beam, and with the same concrete mix, form concrete cubes. This provides opportunity to test the compressive strength of the concrete, the tensile strength of the steel used and the load and failure behaviour of the entire beam. The standard cube test is to be used in accordance to BS8110.

Risk assessment:

- P.P.E required are; Steel toe capped boots, eye goggles, tough gloves and dust masks
- Concrete can cause burns to skin and cement dust inhalation can have harmful effects
- Concrete is heavy so care must taken when transporting it

Equipment and materials required:

- Weighing scales suitable to measure up to 75Kg
- Digital scales for calculating moisture content
- Means to dry aggregate samples to calculate moisture content
- Concrete mixing machine
- Coarse aggregate
- Fine aggregate
- Cement
- Water supply
- Vibrating rod
- Beam, cube crushing machine and rod tension testing facilities
- Slump cone
- Form work for the beam and cubes
- 8mm steel reinforcing rod

Introduction to cube testing

The compressive strength of concrete is controlled by the mix design. Therefore, it is vital to test concrete throughout any construction project. Concrete strength also increases as time passes. This report aims to show this by forming six cubes from the same batch of concrete and test three after 14 days and three after 28 days.

For reliable results from the cube test, the moulds must have completely flat sides to avoid uneven compression whilst testing. If rough surfaces are used between the plates then the results will be unreliable.

Workability will be checked using the standard slump test. Various construction techniques depend on having correct workability such as concrete pumping or spraying.
More details on the slump test can be seen in appendix 1.0.

This report will explain the testing process and the practical mix design; in addition, it will show how time affects the strength of the concrete.

Method for concrete cube lab

The students of the class each had an individual concrete mix design. Each design stated the required values for the following factors:

- Characteristic strength after 28 days
- Proportion of defectives
- Standard deviation
- Cement strength class
- Type of aggregates
- Maximum aggregate size
- Maximum free water to cement ratio
- A range of the desired slump measurement
- Maximum cement content
- Minimum cement content
- Relative density of aggregate
- Percentage of aggregate passing through a 600mm sieve

Only one of the mix designs was used. The chosen mix can be seen in appendix 1.1.

We weighed out the ingredients starting with the course aggregate followed by the gravel and then the fine aggregate.

[Fig 1.0 shows the course aggregate]

The cement was placed in the middle of the ingredients to reduce dust. The batch was then mixed dry to ensure even distribution of the ingredients. The water then added gradually to avoid splashes.

[Fig 1.1 shows the mixed concrete]

The workability of the wet mix was then checked using the slump test (details can be found in appendix 1.0)

[Fig 1.2 shows the slumped concrete, the cone and the rod used to poke each layer]

The distance between the slumped concrete and the cone top was noted.

The six cubes were filled on a vibrating table. This promotes uniform distribution of all ingredients.

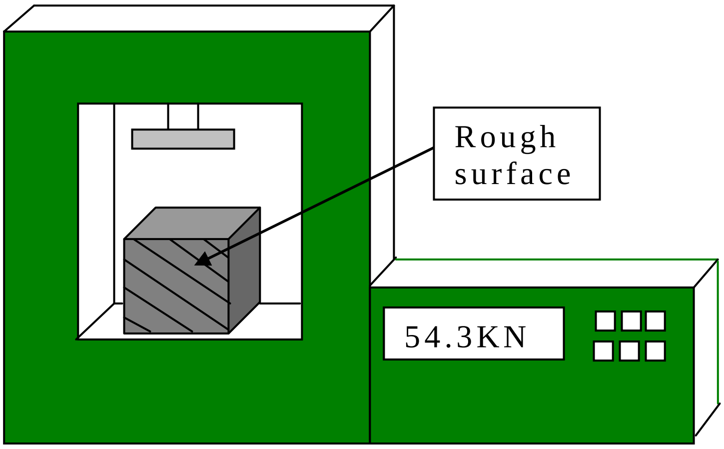
[Fig 1.3 shows the six concrete filled forms on the vibrating table]

We numbered each cube and left them to set.

The standard industry cube test was used (details shown in appendix 1.0). We tested three cubes after 14 days and three cubes after 28 days to see the strength difference. The machine detects when the cube reached its limit and calculated the force.

Before testing, the weight of each cube was recorded and placed into the machine with the rough side facing forward.

[Fig 1.4 shows a diagram of the cube test machine]



Results

Below is a table showing the results of the cube crushing tests.

[Fig 1.5 shows a table of the cube test results]

Cube no.	*Weight(g)*	*Volume(m^3)*	*Density(Kg/m^3)*	*Compressive strength(KN)*	*MPA*
10	*2380*	*0.1*	*2380*	*536*	*53.6*
13	*2405*	*0.1*	*2405*	*526*	*52.6*
15	*2395*	*0.1*	*2395*	*514*	*51.4*
2	*2395*	*0.1*	*2395*	*556*	*55.6*
1	*2395*	*0.1*	*2395*	*524*	*52.4*
8	*2409*	*0.1*	*2409*	*574*	*57.4*

Cubes 10, 15 and 13 were tested after 14 days and cubes 2, 1 and 8 were tested after 28 days. All cubes failed in a satisfactory manner in accordance with BSEN12390-3. The two surfaces that were in contact with the machines plates suffered very little damage. The free air surfaces all had vertical cracks that were equally distributed.

[Fig 1.6 shows a picture of one of the cubes and shows the damage after failure]

Analysis of results

From the table of results we can see that the cubes tested after 14 days tended not to be as strong as those tested after 28 days. Below shows a table of the average strength of the cubes and the differences in strength.

[Fig 1.7 shows the average cube strengths]

	Average compressive strength(MPA)
Cubes tested after 14 days	52.53
Cubes tested after 28 days	55.13
Strength increase	2.6

Fig 1.7 shows a 2.6mpa increase in strength. It is only a small increase but shows that the concrete is becoming stronger as time passed. The concrete may have already begun to reach its peak strength by day 14 of setting explaining the small increase by day 28. The original mix design (which be found in appendix 1.1) had a target mean strength was 55.68mpa. This is slightly more than the average strength of the cubes. If this concrete were to be used it would require alterations to ensure the average value was more than the original design strength.

As each cube failed in approximately the same way it indicates that, the mix was homogenous and had an even distribution of ingredients. The mixing machine was specifically designed for this purpose. Thorough mixing therefore increases consistency concerning properties and how it fails.

Conclusions

The results show that the actual strength of the concrete was less than the target mean strength after 28 days. I expected the actual strength to be more than the design strength for safety and unknown factors. The mix design seems to give values that occur after 28 days, this is shown in the 14-day results clearly.
The mix design is a good prediction of the concretes strength but the practical mixing of the ingredients needs to be accurate. This is likely to be the source of our errors, as I do not believe that the mix design process would be so close to the real strength.
This experiment to me highlights how easy it is to accumulate errors throughout the mixing of the concrete and why it is vital to conduct on site tests of each batch of concrete to ensure it meets the requirements of the original design.

Introduction of reinforced beam exercise

A concrete beam requires reinforcement because concrete does not behave well in tension. In fact, the tensile strength is just 1/10 of its compressive strength.

During the design process, an idealised model of how steel and concrete behaves during stress and strain is used to calculate the position of the reinforcement. Unfortunately, real life tends not to be ideal and therefore means each beam needs to be tested to ensure that the criterion has been met and that it will fail in the correct manner.

This report will look at the design and testing process. It will also compare theoretical strength with actual strength and highlight why testing is so crucial to ensure satisfactory failure. Warning that a building is about to collapse is vital to give the occupants time to escape. By designing the structural members correctly, potential loss of life is avoided.

Method for reinforced beam

The reinforcement design utilises the idea that for a balanced design you need the compressive concrete force acting on the top to equal the tension force acting on the bottom. However, for a reinforced beam to give warning before failure we require under-reinforcement where the steel reaches its peak before the concrete. Using the known equation for balanced design, we see that:

$$x = 0.617d$$

$$\therefore d = 180mm$$

$$\therefore x = 0.617 * 180 = 111.06mm$$

Anything less than this value will be under-reinforced.
The concrete mix consisted of the following amount of ingredients for a sample batch:

- 70KG coarse aggregate
- 40KG fine aggregate
- 26KG cement
- 13KG water

The aggregate had been stored outside and therefore already had water in it from the rain. This had to be accounted for to avoid too much water going into the mix and changing the mix design.

[Fig 2.0 shows the pans used to weigh the wet and dry aggregate]

The moisture content of the aggregates was calculated using the following equation:

$$\frac{wetmass - drymass}{drymass - weightofpan}$$

The coarse aggregate had a moisture content of 1.7% and the fine aggregate had a moisture content of 18%. The moisture content was deducted from the water amount.

$13Kg - 1.19 - 7.2 = 4.6Kg$ Of water

Coarse aggregate- $70 * 0.017 = 1.19$
$\therefore 70 + 1.19 = 71.19Kg$

Fine aggregate- $40 * 0.018 = 7.2$
$\therefore 40 + 7.2 = 47.2Kg$

Two batches were made and therefore the above values halved:

- 35.6Kg of coarse aggregate
- 23.6Kg fine aggregate
- 2.3Kg of water
- 13Kg cement

The mix was dry mixed first to ensure homogenous mixing and then the water was added with cement placed centrally to reduce dust.

The water was added and mixed thoroughly. It was then placed in the formwork and into three cube moulds and both was vibrated by a vibrating rod to compact the mix uniformly.

[Fig 2.1 shows the concrete being placed into the formwork and vibrated.]

The beam then cured for 28 days.

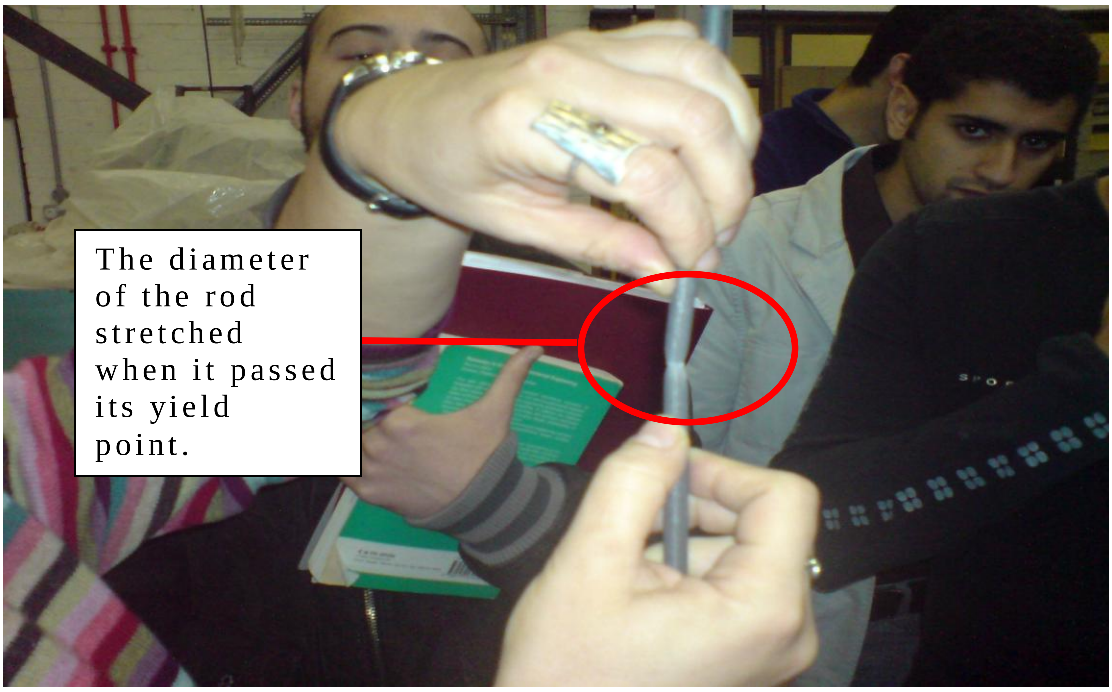
The testing process comprised of the following:

- A cube test to find out the compressive strength of the concrete
- Strength test of the steel
- Loading test of the beam

The cubes were weighed before they were crushed for density calculations. Unfortunately, one of the cubes was inserted into the machine incorrectly with the rough side in contact with the plates. This cube was void from the test.

A piece of the same steel used in the beam was subjected to a strength test by a machine that pulled it until yield and then breaking point was reached. The machine calculated the force.

[Fig 2.2 shows the steel rod after the strength test]

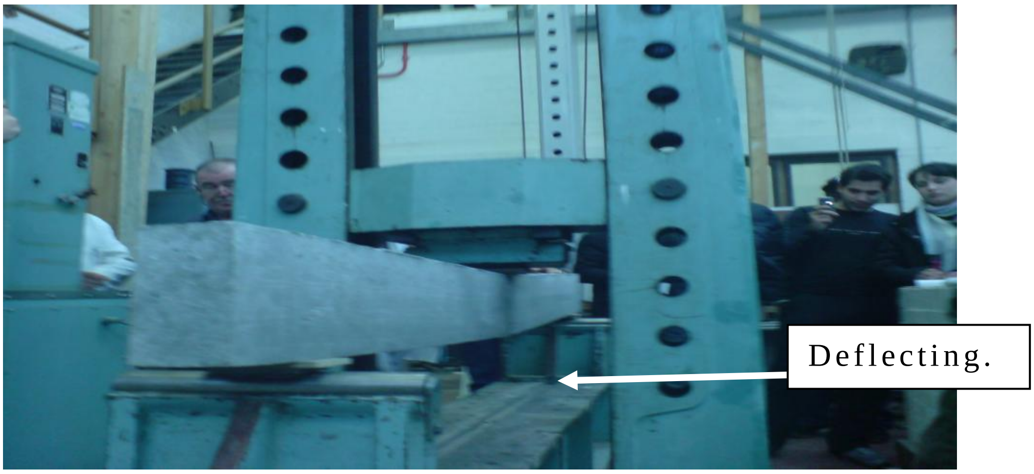


The beam was loaded onto rollers with equal overhang both sides. A steady constant point load was applied to the centre of the beam. The deflections and cracks were observed until the beam failed.

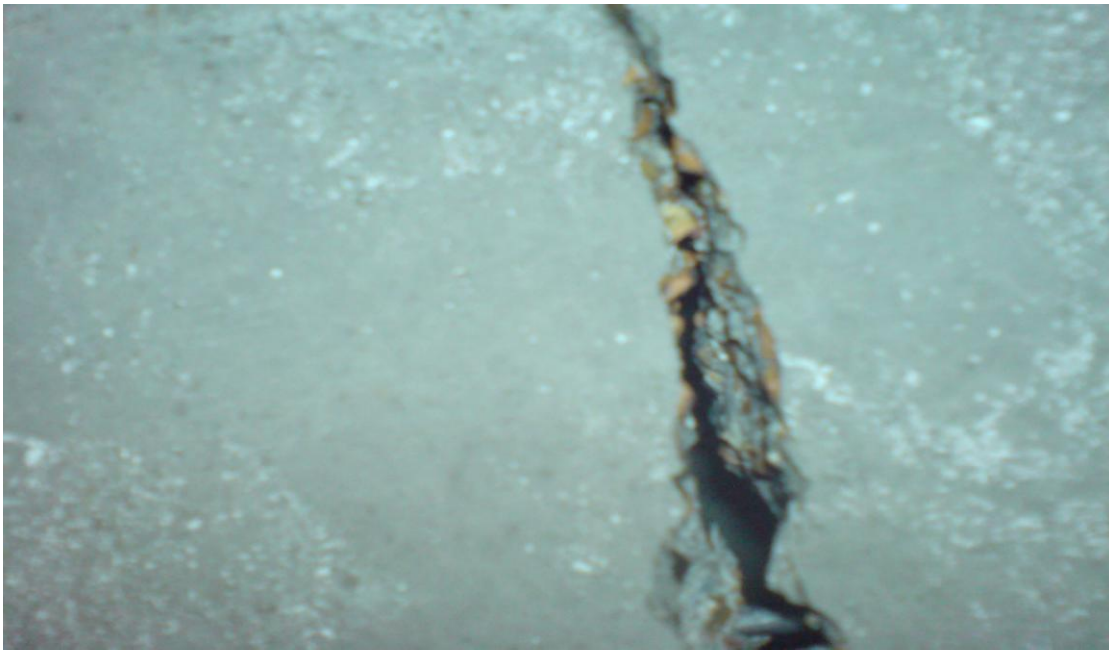
Results

The beam failed satisfactory at a load of 1.2ton (imperial) which converted to KN equals 11.96KN and would have provided warning of its imminent failure. This is because it was under reinforced.

[Fig 2.3 shows the beam deflecting under load]

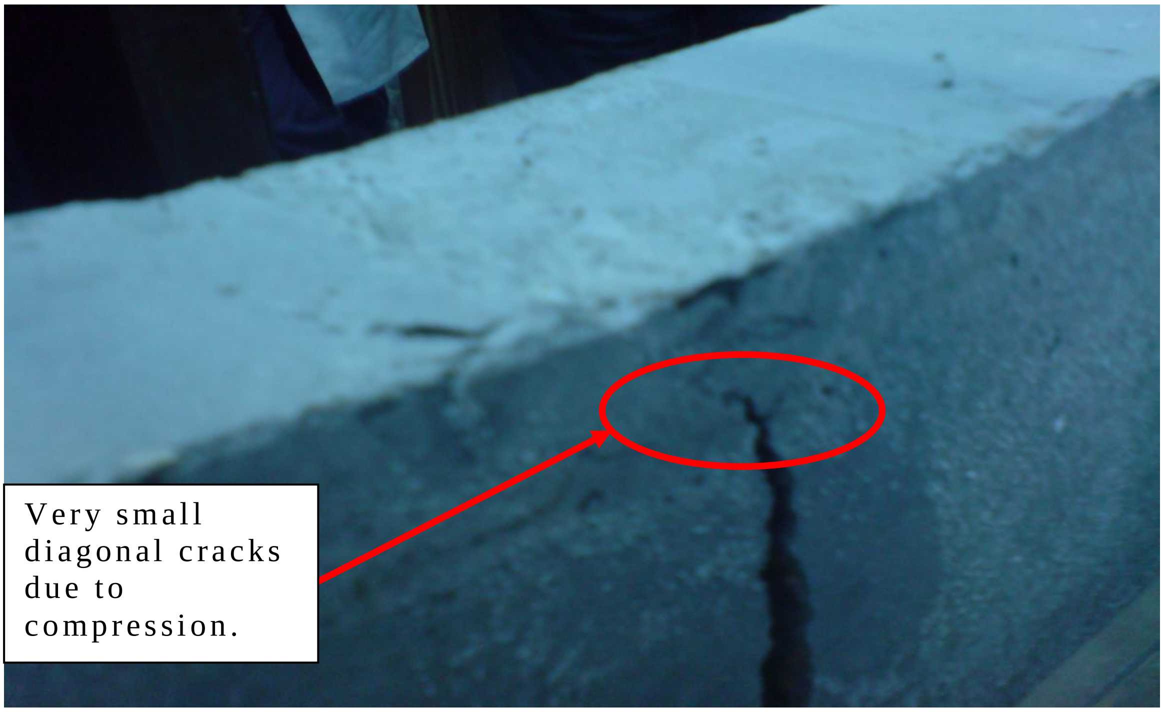


[Fig 2.4 shows the tension cracks in the beam]



During the testing cracks first appeared at the bottom of the beam (Fig 2.4) in the centre due to tension. These cracks became larger as the deflection increased. There were very small cracks in the compression region of the beam. These cracks appeared to be running diagonally rather than vertically like the tension cracks.

[Fig 2.5 shows the tiny compression cracks]



[Fig 2.6 shows table of results for cube crushing test]

Cube	Weight(g)	Strength(KN)	MPA
3	2396	619	61.9
9	2415	Void	Void
12	2395	589	58.9

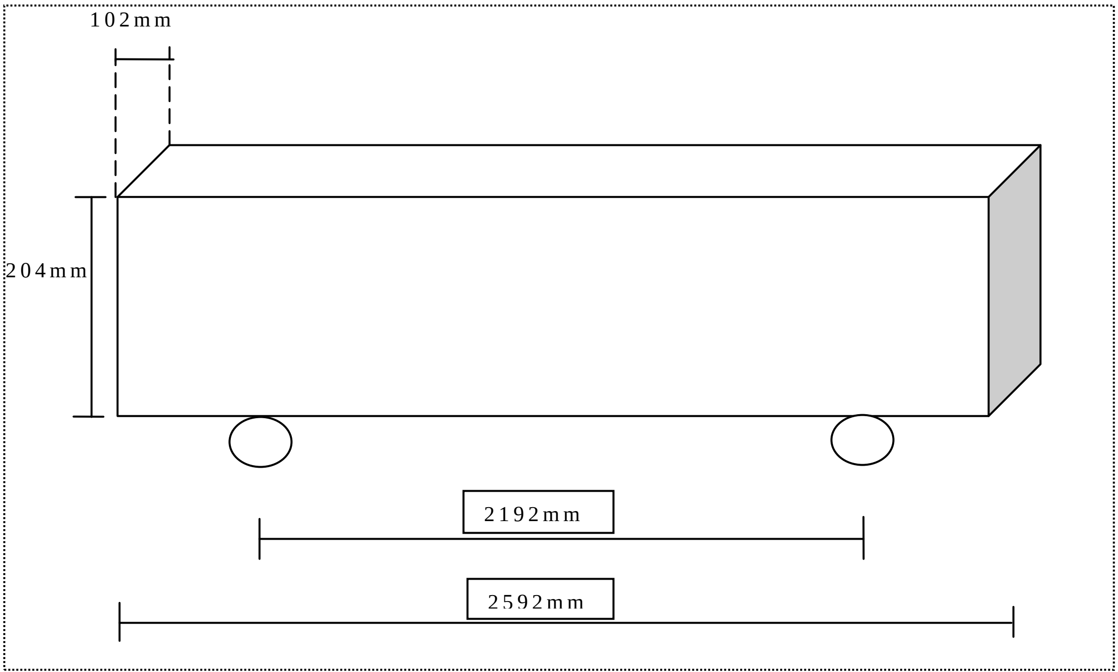
The steel rod had a yield point of 5200lbs and a break point of 5700lbs which, when converted to KN becomes 23.1KN and 25.4KN respectively.

Result analysis

For the following calculations, please note that:

- Average concrete cube density(ρc) 2402Kg/m^3
- Average cube strength (f_{cu}) 60.4N/mm^2
- Yield strength of steel (f_y) 459.6

Test beam dimensions:



For a symbol key, see appendix 1.3.

Certain factors have to be used for the following calculations:

- **1.5** - Safety factor for the cube strength (γm)
- **0.85** - Factor for x. this changes the concrete stress graph into a rectangle shape rather than dealing with integration
- **0.67** - Factor for cube strength. this accounts for the relationship between flexural member strength and the cube strength

Cross sectional area of steel bars:

$$As = 2 * \frac{\pi d^2}{4} \Rightarrow 2 * \frac{3.14 * 8^2}{4} = 101 mm^2$$

Self-weight of beam:

$$W(KN) = volume * density * gravity \Rightarrow (2.592 * 0.204 * 0.102) * 2402 * 9.81 = 1270.9 N$$

Or **1.271** KN

Force in compression (concrete):

$$F_c[N] = \frac{0.67 f_{cu}}{\gamma m} * 0.85x * b = \frac{0.67 * 60.4}{1.5} * 0.85 * x * 102$$
$$\Rightarrow F_c = 2339x(N) \approx 2.34x(KN)$$

Force in tension (steel):

$$F_t[N] = \frac{A_s * f_y}{\gamma_s} = \frac{101 * 459.6}{1.15} \Rightarrow f_t = 40364.9N$$

Or **40.364** KN

For equilibrium:

$$f_c = f_t \Rightarrow 2.34x = 40.4 \Rightarrow x = \frac{40.4}{2.34}$$
$$\therefore x = 17.3mm$$

Internal lever arm:

$$z = d - \frac{0.85x}{2} \Rightarrow 180 - \frac{0.85 * 17.3}{2} = 172.64mm$$

Ultimate moment capacity:

$$m_u = f_t * z \Rightarrow 40.4 * 0.17264 = 6.97KNm$$

Applied moment from self-weight:

$$M_{sw}[KNm] = \gamma_f * \frac{W}{2}\left(\frac{Le}{2} - \frac{L}{4}\right) = 1.4 * \frac{1.271}{2}\left(\frac{2.192}{2} - \frac{2.592}{4}\right) = 0.39KNm$$

Available moment for point load:

$$M_p = 6.97 - 0.39 = 6.58KNm$$

Therefore, the point load calculated from moment:

$$6.58 = \frac{p_1 * Le}{4} \Rightarrow 6.58 = \frac{p_1 * 2.192}{4}$$

$$\therefore P_1 = \frac{4 * 6.58}{2.192} = 12KN$$

The calculated result 12KN is 0.04KN above the actual strength of 11.96KN

Conclusions

From the above calculations, we can see that the actual strength is less than the calculated strength. I expected the actual strength to be more than the calculated strength based on safety. Throughout the above calculations, safety factors were added as a means of ensuring that any designs had a tolerance for possible unknown factors. Saying that the calculations rely on the experimental data, which could have been victim to human error. One of the cubes were incorrectly loaded which meant only two results were useable. This affected the average cube density. The value for f_y (yield strength of steel) requires the load at which the steel entered the plastic region and began to “neck”. It is possible that we noticed this too late and therefore recorded a reading after this had begun. Yield strength of 459.6mpa is high and this could be the reason for error.
On the other hand, it could be argued that the calculations are extremely close to the actual results, which would indicate a high degree of accuracy, but I believe over-engineering every design is important to allow for unknowns, sudden loads, acts of god etc. This way you can always be sure the structure will work as originally intended.

References and acknowledgements

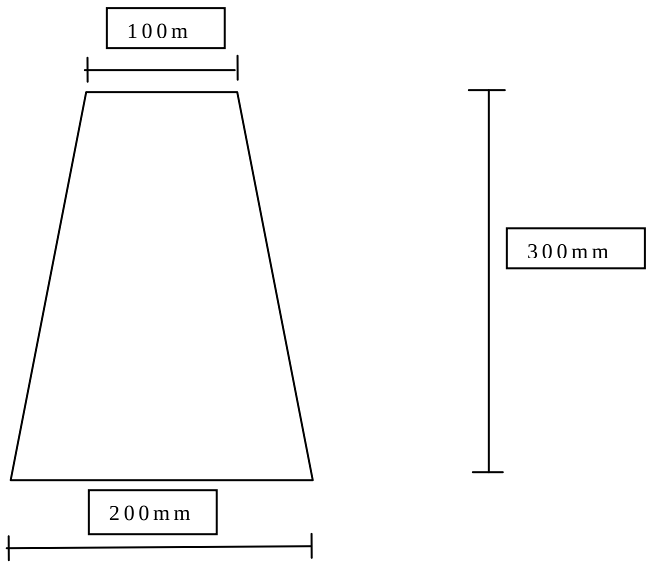
CN248 lecture notes ‘07/’08 by Dr Freiderike Günzel

Appendix 1.0

BS8110-Slump and cube test

Slump test

When using concrete as a construction material it is often essential to have an idea of how workable the concrete is. Spraying or pumping concrete requires an easy flowing mix. The slump test is a test is a way of quantifying the workability of the concrete mix.
It is widely used because it is very cheap and easy to use on site.
To conduct a slump test you simply obtain the standard sized cone (shown below)



The following steps are then taken:

- Mix a sample batch of concrete
- Fill the cone with three equal layers of concrete
- After each layer is placed into the cone it must be prodded 25 times with a rod approximately 10mm in diameter
- Scrape off the surface
- Carefully remove the cone
- Measure the distance from the top of the cone and the top of the concrete
- The distance is the slump value

As a guide, here is a list of the slump ranges:

- Low workability – 0-50mm
  This is for large concrete sections

- Medium workability - ≅75mm
  General-purpose concrete, beams, columns

- High workability - ≅125mm
  Pumping concrete, highly reinforced sections

Cube test

To calculate the compressive strength we use the following equation:

$$f_{cu} = \frac{F}{A_c}$$

Where:

- A_c is cross sectional area of the contact cube sides
- F is the maximum load(N)
- f_{cu} is the compressive strength in mpa (N/mm^2)

The cube test simply crushes a standard sized cube made from a metal mould. This mould must have smooth surfaces and the cube must be placed into the cube-crushing machine with the rough surface facing outward. If a rough surface has contact with the machines plates then unreliable results will occur.
The cube test does require a specialist machine and is therefore more expensive than the slump test but more important.

The cube test gives a value for the compressive strength of the concrete and is a check to ensure the original design strength is achieved.

The cube must fail in a specific way to satisfy BS8110:

- The cracks on the exposed sides should be approximately equal.
- The cube sides that were in contact with the machines plates should have little damage.

If the cubes are irregular shapes after the test or noticeable damage has occurred to the cube sides that had contact with the machine plates then this unsatisfactory. Tensile cracks in the cube would also indicate an unsatisfactory result. This could be caused by incorrect loading of the cube into the machine or possibly a problem with the machine itself.

Appendix 1.3

Table of Symbols and their meaning:

Symbol	Meaning
γ_m	Factor of safety cube strength
F_{cu}	Cube strength
F_y	Yield strength of steel
W	Self weight of beam
F_c	Force in compression
F_t	Force in tension
γ_s	Concrete strength safety factor
A_s	C.S.A longitudinal tension steel bar
z	Internal lever arm
m_u	Ultimate moment capacity
m_{sw}	Applied moment from self weight
γ_f	Self weight safety factor