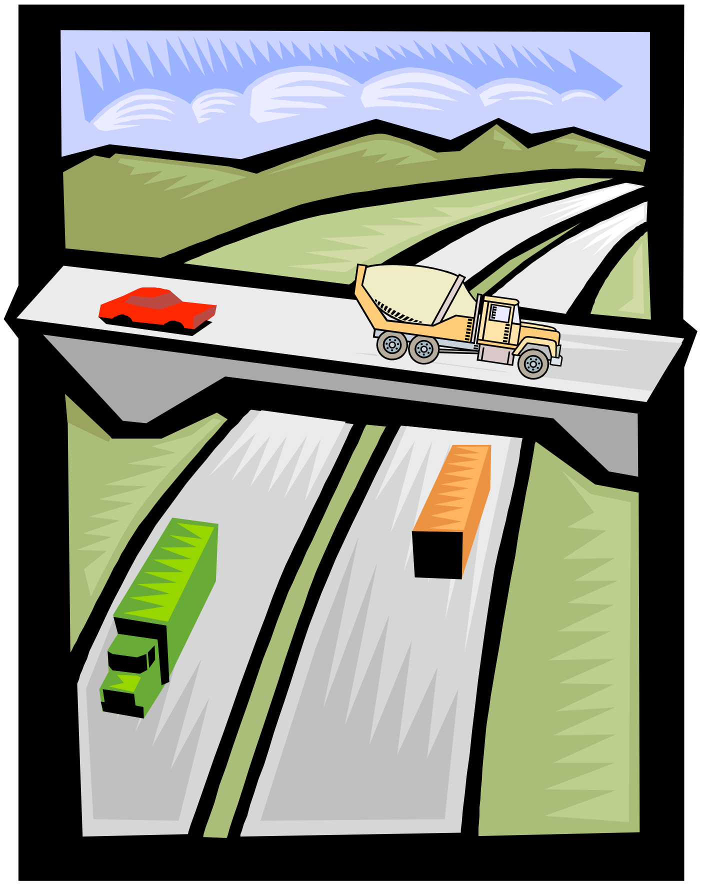
centre de développement pédagogique
pour la formation générale en science et technologie

Working document



CONCRETE

TEACHER'S GUIDE

June 2008

Contents

Safety capsule

Cement and concrete




1. Careful! Prepared cement and concrete are corrosive.
2. In case of contact, wash skin then wash your hands at the end of the manipulations.
3. Wear safety glasses to protect yourself from splashing. In case of contact with eyes, rinse them immediately using the eyewash that is present in class.
4. Use a mask if cement powder is suspended in the air. If you manipulate the powder carefully, wearing the mask will not be necessary.
5. Wear protective clothing to avoid accidental projections.
6. Clean the work surface after manipulations to avoid potential splashing. A solution of hydrochloric acid may be used to clean tough deposits.
7. Do not dispose of leftover cement or concrete in the drain, since this could block it. Instead, dispose of waste in a plastic bag in the garbage. The water from the final rinse may be put down the drain using strongly flowing water.




Ensure that any modifications to this safety capsule do not compromise student safety. The person at fault would have to assume responsibility for his choices.

Introduction

1. Before reading the present guide, we suggest you read two other documents: the overview of this task « *concrete_overview_AST.pdf* » and the student booklet « *concrete_student_AST.pdf* ». The overview will allow you to better situate this task within the program.
2. The beam, which is at the center of this LES, is easy to make and allows the possibility of dealing with a surprising number of concepts. Indeed, the student will have to, among other things, balance chemical equations, study different mechanical constraints, calculate forces and mechanical advantages.
3. Eight periods are foreseen for this activity:
    - Period 1 : Context and mandate
    - Period 2: Learning activities I and II
    - Period 3: Learning activities III and IV
    - Period 4: Learning activities V and VI
    - Period 5: Learning activity VII and designing the beam
    - Period 6: Building the forms and pouring the concrete
    - Period 7: Testing the beams
    - Period 8: Commission of inquiry and improvements
4. This LES could be undertaken in teams of 2 students.

I- Laboratory about cement hardening

During this simple manipulation, the student will discover that heat is released when cement and concrete cure. Concrete curing is therefore a chemical reaction.
A disposable calorimeter made out of expanded polystyrene may be used (see adjoining photos). A disposable plastic test tube, partially filled with water, can be buried in the concrete. A thermometer plunged in this water will detect variations in temperature and will be protected from the compression of the concrete because of its distance from it.

During this manipulation, quick-set leveling cement must be used. Since the cement sets more quickly (15 to 45 minutes), the elevation of temperature will be more obvious than with conventional type 10 cement.
The graph in question 4 of the following section was drawn from this experiment. (See student booklet for the graph).

II- Questionnaire about cement hardening

Question 1 *A chemical transformation, since heat is released.*

Question 2
Since water began the chemical reaction, it is likely that water plays a role until the end of the cement hardening. It is thus preferable to keep the cement damp.

Question 3
Heat is thermal energy. Temperature is a measure of the degree of agitation of the particles.
If the same quantity of heat is given to two different objects, their temperature will probably not rise the same way. The mass and the specific heat of the objects must be taken into consideration.

Question 4

(The reaction releases less heat than heat is lost in the environment)	(D)
(The reaction releases heat at a constant rate)	(B)
(The reaction releases as much heat as heat is lost in the environment)	(C)
(The reaction begins to release heat)	(A)

Question 5
The cement will become dehydrated and the chemical reaction of curing will stop. Its resistance will be greatly affected.

Question 6
*Hardening will be accelerated if the grains are small. The chemical reaction occurs when the reagents come into contact. By breaking the grain in two, for instance, we create two new surfaces by which the chemical reaction can take place. The more the grains are fractured, the more explosive the reaction will be. It is not for nothing that we make canon **"powder"**.*
By increasing the temperature, we can also accelerate setting. We must not increase it to the point that the cement becomes dehydrated, however. Finally, adding an accelerator (a catalyst) like calcium chloride ($CaCl_2$) can also accelerate the process.

Question 7 *The cement attains 75% of its resistance after 7 days.*

III- Questionnaire about the composition of concrete

Question 1
Salt is the aqueous solution.

Question 2
Water is the solvent.

Question 3
The salt will reside between the particles of water, in the chinks.

Question 4
A solution is saturated when all the chinks are filled by the aqueous solution.

Question 5
A mass of 360 g of table salt can be dissolved for each litre of water at 20 °C.

Question 6
The solubility of table salt at 80°C is approximately 397g/L. It will be impossible to dissolve the salt entirely. The excessive salt will remain visible and solid.

Question 7
Cement is a powder that can react with water to form a solid. Cement is one of the substances present in concrete.
Concrete is composed of cement, granulates[1] and water.

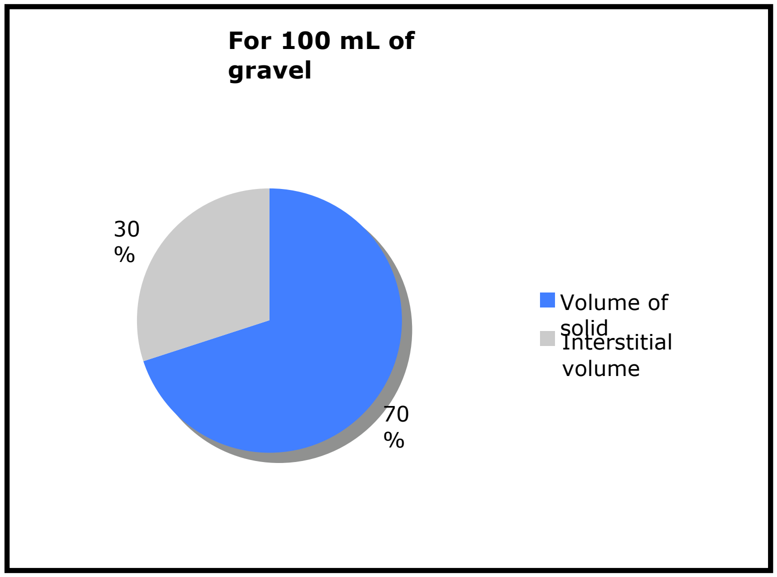
[1]***GRANULATE:*** *Set of inert materials that make up concrete, the mortar.*

Question 8

Example of interstitial volume for 100 ml of a specific type of gravel.

Interstitial volume: 30mL/100 mL of gravel

Percentage of air in this gravel: 30% v/v

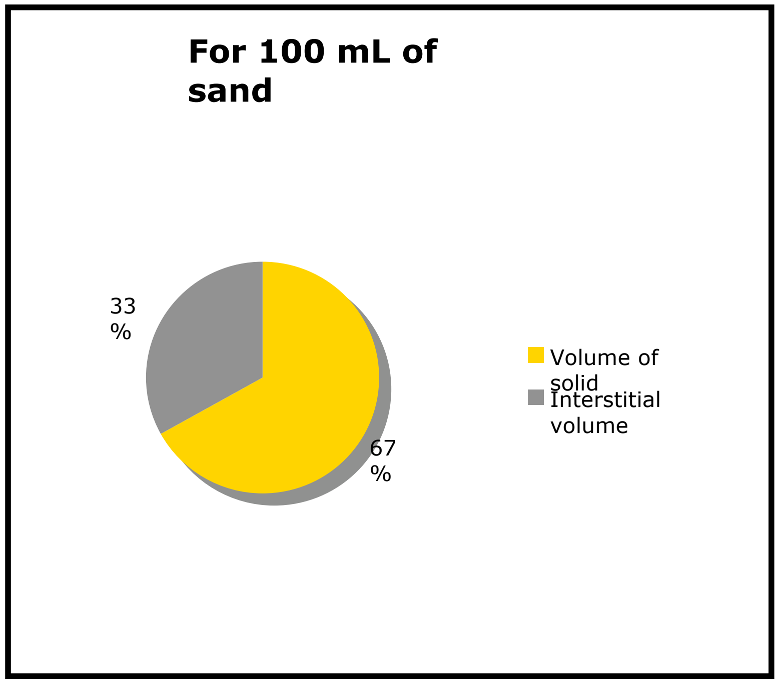


Question 9

Example of interstitial volume for 100 ml of a specific type of sand.

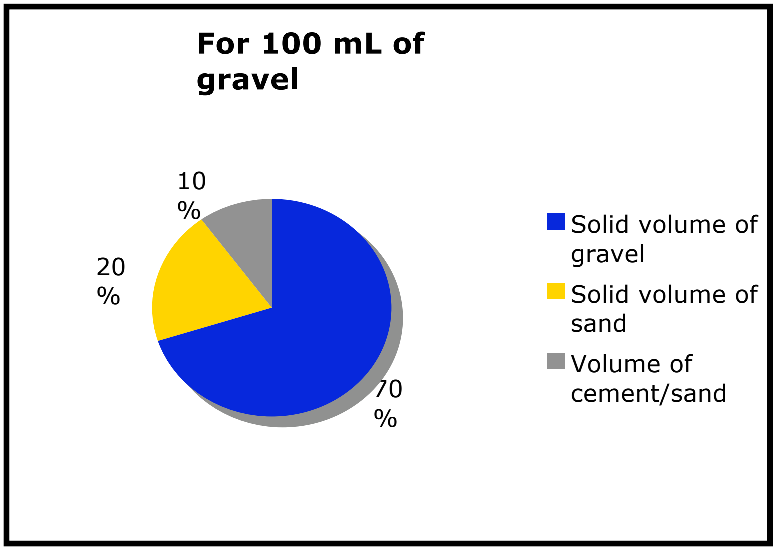
Interstitial volume: 33mL/100 mL of sand

Percentage of air in this sand: 33 % v/v



Question 10

Here is the recipe we could obtain considering the previous questions.



Recipe for 100 mL of gravel	*Gravel solids*	*Sand solids*	*Cement*	*Water*
Ratios found experimentally (%)	*70*	*20*	*10*	*≈5 ?*

Thoughts for 100 mL of gravel	*Gravel*	*Sand*	*Cement*	*Water*
Real measured volumes (mL)	*100*	*30*	*10*	*≈5 ?*
Volumes including a safety factor of 100% more sand (mL)	*100*	*60*	*20*	*≈10 ?*
Volumes including a safety factor of 50% more cement (mL)	*100*	*60*	*30*	*≈15 ?*

Example of a secret recipe	*Gravel*	*Sand*	*Cement*	*Water*
Approximate simplified volumes (mL)	*90*	*60*	*30*	*≈15 ?*
Ratio	***3***	***2***	***1***	*≈0,5*
Volume (mL)	*450*	*300*	*150*	*≈75*

Notes

- *The quantity of water added is quite variable. Some recipes recommend a cement/water ratio of 1 to 0.5. Practically, such a recipe produces concrete that is much too pasty. The cement/water ratio that you will likely use will probably be closer to 1 to 1. The absorption of water by the different granulates[1] is probably the cause. The quantity of water should therefore be adjusted empirically.*
- *The gravel used should be solid; otherwise the concrete will be weakened. In fact, concrete can not be more solid than its component parts. Granulates used should not be able to be scratched by anything other than steel or a harder substance.*
- *The cleanliness of the granulate is also important. Substances of organic origin do not have great mechanical resistance. In addition, these substances can impede adhesion between concrete's component parts.*

IV- Questionnaire about concrete curing

Question 1 (To be verified experimentally)

No, the mass of the concrete does not change; there is mass conservation as long as no evaporation has occurred.

Question 2

No, the number of atoms is the same before and after the chemical reaction. If the number of atoms had changed, the mass would have changed.

Question 3

Name	Formula	Calcium	Oxygen	Silicon	Iron	Aluminium
Dicalcium silicate	$(CaO)_2SiO_2$ { simplified } or $2CaO{\cdot}SiO_2$	2	4	1	0	0
Tricalcium silicate	$(CaO)_3SiO_2$ { simplified } or $3CaO{\cdot}SiO_2$	3	5	1	0	0
Tricalcium aluminate	$(CaO)_3Al_2O_3$ { simplified } or $3CaO{\cdot}Al_2O_3$	3	6	0	0	2
Tetracalcium aluminoferrite	$(CaO)_4Al_2O_3Fe_2O_3$ { simplified } or $4CaO{\cdot}Al_2O_3{\cdot}Fe_2O_3$	4	10	0	2	2

Question 4

	Reagents	Products
	$(CaO)_3Al_2O_3$ + **6** H_2O $\longrightarrow$	$Ca_3Al_2O_6(H_2O)_6$
O	*7 → **12***	***12***
H	*2 → **12***	***12***
Ca	***3***	***3***
Al	***2***	***2***

Question 5

	Reagents	Products
	$\mathbf{2}\ (CaO)_2SiO_2 + \mathbf{4}\ H_2O \longrightarrow$	$Ca_3Si_2O_7(H_2O)_3 + Ca(OH)_2$
O	*5 → 8 → **12***	***12***
H	*2 → **8***	***8***
Ca	*2 → **4***	***4***
Si	*1 → **2***	***2***

Question 6

	Reagents	Products
	$\mathbf{2}\ (CaO)_3SiO_2 + \mathbf{6}\ H_2O \longrightarrow$	$Ca_3Si_2O_7(H_2O)_3 + \mathbf{3}\ Ca(OH)_2$
O	*6 → 12 → 14 → 15 → **16***	*12 → 14 → **16***
H	*2 → 4 → 8 → 10 → **12***	*8 → 10 → **12***
Ca	*3 → **6***	*4 → 5 → **6***
Si	*1 → **2***	***2***

Question 7

It is preferable to keep it moist while it is curing, for the water participates in the chemical reaction and is integrated in a larger molecule.

V- Questionnaire about concrete as a building material

Question 1 (To be verified experimentally)
Concrete is base.

Question 2 (To be verified experimentally)
Concrete's pH is variable. A pH of 13 could be measured in healthy concrete.

Question 3
The preceding chemical equations indicate that calcium hydrochloride $Ca(OH)_2$ is formed when concrete is hydrated. The presence of a basic element such as this one increases the level of pH of the concrete.

Question 4

a) *The metals react with the oxygen (O_2)*

b) *The products formed are oxides (CuO, Al_2O_3, Fe_2O_3)*

c) *The metals lose electrons.*

d) *Rain water, with its mineral salts, may promote the mobility of the electrons.*

Question 5
Since acids react with metals, a low pH would promote corrosion.
Example : $2HCl + Mg \rightarrow H_2 + MgCl_2$

Question 6
No, it is not necessary to protect the reinforcements. Since its pH is superior to 7, concrete is a protective environment for the reinforcements. Only the surface reinforcements exposed to the air and to the weather will rust.

Question 7

- *Soft-iron contains very little carbon ≈(- de 0,025%)*
- *Steel contains significantly more ≈(0,025 à 2,1%)*
- *Cast iron contains even more ≈ (+ de 2,1%)*

Question 8

Thermal treatment is used. With this technique, the precipitation of carbon can be controlled when making steel. With relatively quick cooling, the carbon atoms will remain trapped in the iron matrix and cause hardening.

Question 9

Steel is less ductile and more rigid than iron. Reinforcements made out of iron would stretch too much and cause the concrete to flake.

Question 10

When steel oxidises, its volume increases since oxygen atoms are added.

Question 11

If the reinforcements are not adequately buried in the concrete, they will oxidise and their volume will increase, which will break the surface of the concrete. This process will be repeated with the new exposed surface and so on.

Question 12

These substances will increase the volume by reacting with the concrete and will promote its disintegration.

VI- Questionnaire about the mechanics of concrete

Question 1 (To be verified experimentally)
The distance between the upper spots is reduced.

Question 2
The distance between the lower spots increases.

Question 3
A force of compression appears in the upper section of the beam.

Question 4
A force of traction appears in the lower section of the beam.

Question 5
Since concrete is 8 times weaker in traction than in compression, we must spare it in traction zones. That is why we must add reinforcements to the lower portion of the beam.

Question 6 (To be verified experimentally)
The bottom hole allows the most water to escape.

Question 7
The pressure seems stronger on the bottom.

Question 8
The pressure is stronger at the bottom of the carton because there are more water particles above this hole. For the same reason, atmospheric pressure is higher at ground level than at the top of a mountain.

Question 9
The forms must be stronger at the bottom.

Question 10
You must simply allow the lower wall to harden before pouring the second wall. That way, the pressure at the bottom of the forms is limited.

Question 11

The reinforcements are allowed to rust to make them rougher. That way, adhesion between the concrete and the steel is increased. Once they are protected by the concrete, oxidation of the steel reinforcements will stop.

Question 12

These striations increase adhesion between the concrete and the reinforcements.

Question 13

A simple way to decrease the organic burden is to decant them in the presence of water. Indeed, the residues should have a lower density than granulates and water.

Question 14

Archimedes' Principle:
Any body wholly or partially submerged in a fluid is buoyed up by a force equal to the weight of the fluid displaced.

Question 15

Granulates will tend to rise and float on top of the concrete.

Question 16

Air bubbles will tend to rise and exit the concrete.

Question 17

If air bubbles stay trapped under the reinforcements, the concrete will be poorly attached and adhesion will be reduced.

Question 18

A boat will sink until it has displaced the equivalent of its mass in the water.

Question 19

The reinforcements will sink to the bottom.

Question 20

The reinforcements need to be held up and attached to supports.

Question 21

In order for the concrete to surround the reinforcements completely it will need to be stirred using a vibrator. Concrete can be said to be "vibrated". In the case of our beam, a rapid agitation of the form will do.

Question 22

The mass of the gold bar is:

$\rho = m/V \rightarrow m = \rho \bullet V \rightarrow m = 19.3 g/cm^3 \bullet 1000 cm^3 \rightarrow m = 19\,300 g = 19.3 kg$

The mass of the gold bar in water is: (Density of water = 1 g/cm³)

$Mass_{\text{of the displaced water}} = 1000 cm^3 = 1000 g = 1 kg$

$Mass_{\text{in water}} = Mass_{\text{in the air}} - Mass_{\text{of the displaced water}}$

$Mass_{\text{in water}} = 19.3 Kg - 1 kg = 18.3 kg$

VII- Questionnaire about testing a beam

Question 1

Mass measures the quantity of matter and should be measured in grams. Weight is the force of attraction of a planet on an object and should be measured in Newton. In interstellar vacuum, for example, an object has mass, but its weight is nil. It is frequent in every day life to confound the two terms.

Question 2

Newton's second law:

The net force on an object is equal to the mass of the object multiplied by its acceleration. $\Sigma F = m \cdot a \rightarrow F = m \cdot a$ *(Simplified)* $\rightarrow F = m \cdot g$ *(Considering a beam)*

Force is expressed in Newton (N) or (kg•m/s²), the mass in kilograms (kg) and acceleration in metres per seconds squared.

Question 3

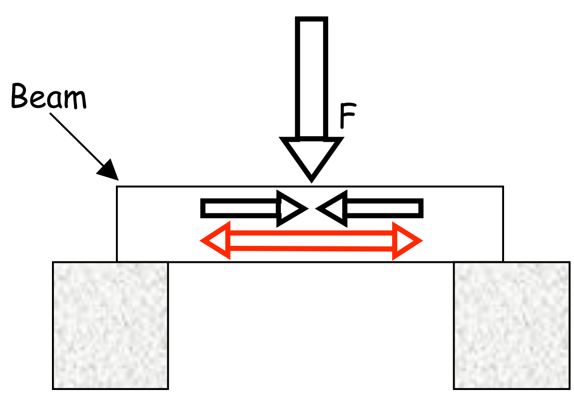
The force sustained by the apple is: $F = m \cdot g \rightarrow F = 0.2kg \cdot 9.8m/s^2 \rightarrow F = 1.96N$

Question 4

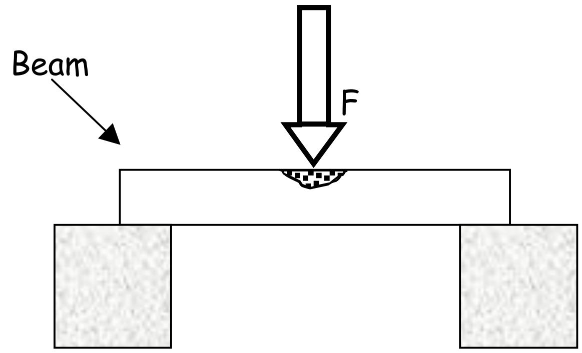
Since the beam is immobile, the sum of all the forces applied on the beam should be nil. Here is the calculation of the missing force:

$\Sigma F=0 \rightarrow F_1 + F_2 + F_3 = 0 \rightarrow F_2 = -(F_1 + F_3) \rightarrow F_2 = -F_1 - F_3 \rightarrow F_2 = -(-10N) - 5N \rightarrow F_2 = 5N$

Question 5

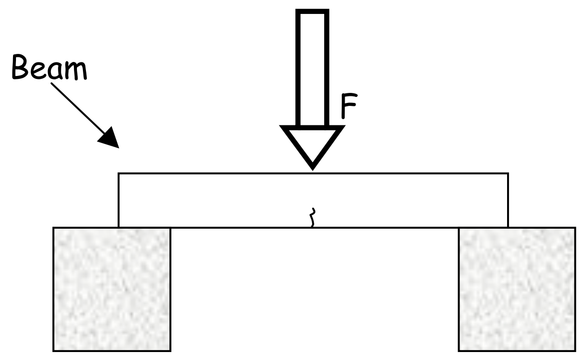


Question 6



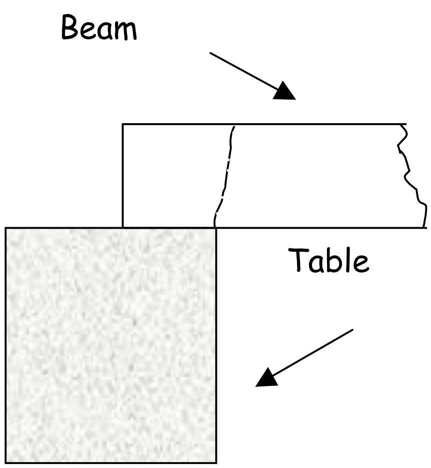
The excessive force of compression appears at the top of the beam. You should see an area where the concrete is simply crushed. Most often this area is located at the center of the beam's span.

Question 7



The excessive force of traction appears on the bottom of the beam. You should see a fissure appear, most often located at the center of the beam's span.

Question 8



The excessive shearing constraint would appear at the end of the beam. You should see a fissure appear opposite the corner of the table. The orientation and shape of the fissure may change in relation to the presence of reinforcements at the end of the beam.

Question 9

a) *The hammer's mechanical advantage is:* $A_m = L_m / L_r \rightarrow A_m = 30cm/10cm = 3$

b) *The force sustained by the nail is three times greater than the force applied on the handle.*

c) *The force necessary to pull the nail out is:*
$A_m = F_r/F_m \rightarrow F_r = A_m \cdot F_m \rightarrow F_r = 3 \cdot 50N \rightarrow F_r = 150N$

Question 10

a) *The mechanical advantage of the beam is:* $A_m = L_m / L_r \rightarrow A_m = 30cm/5cm = 6$ b) *The necessary drive force is:* $A_m = F_r / F_m \rightarrow F_m = F_r / A_m$ $F_m = 120N / 6 \rightarrow F_m = 20N$ c) *The mass is:* $F = m \cdot g \rightarrow m = F/g$ $m = 20N / 9,8m/s^2 \rightarrow m = 2,04kg$	d) *The mechanical advantage of the beam is:* $A_m = L_m / L_r \rightarrow A_m = 30cm/3cm = 10$ e) *The necessary drive force is:* $A_m = F_r / F_m \rightarrow F_m = F_r / A_m$ $F_m = 120N / 10 \rightarrow F_m = 12N$ f) *The mass is:* $F = m \cdot g \rightarrow m = F/g$ $m = 12N / 9,8m/s^2 \rightarrow m = 1,22kg$

d) *The higher beam, the one whose height 5 cm is the one that supports the greatest mass.*

e) *The mechanical advantage of a hammer must be as large as possible so that the user's force will be multiplied.*

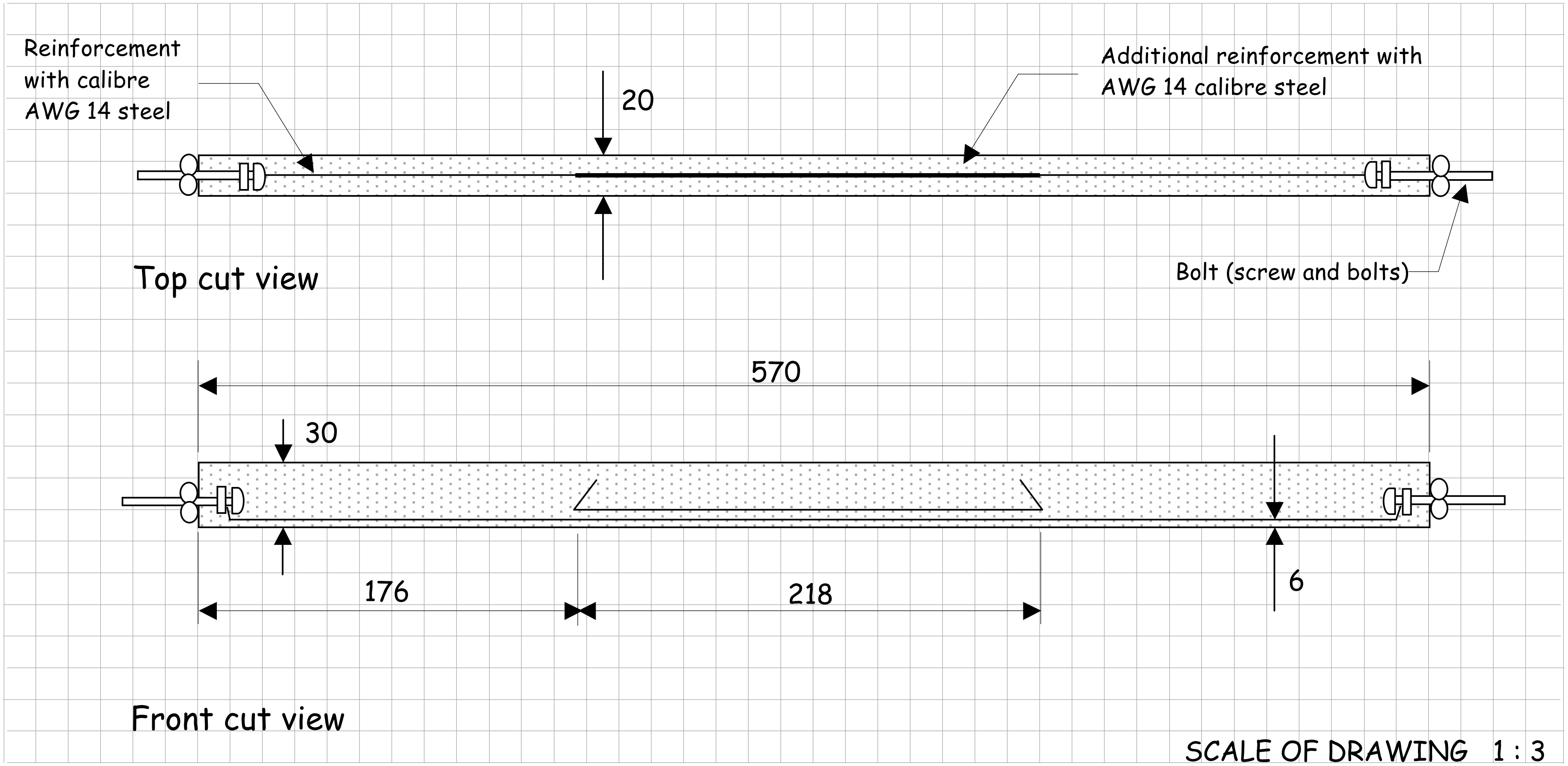
f) *The mechanical advantage of a beam must be as small as possible so that the reinforcements are spared and are thus submitted to a smaller force.*

g) *By installing the reinforcements as low as possible within the beam, we increase the length of resistance* (L_r) *the effect of which is to lessen the mechanical advantage* (A_m).

Designing your beam

(See following page)

Example of drawings of a beam with its reinforcements



Data regarding the beam

Names of team members: *Martine Curie and Luc Einstein* **Group No.:** *08*

Concrete recipe Volume cement (mL): *150* Volume gravel (mL): *300*

Volume sand (mL): *300* Volume water (mL): *100*

Pour date: *14 / 05 / 08* Curing time: *7 days* Ambient humidity : 95%

Mass of the beam: *700g* Mass supported by the beam: *18700g* Resistance Factor: *26.7*

Making the beam

Making the forms and installing the reinforcements
See the document entitled « concrete_ranges_AST.pdf »

Notes about pouring concrete

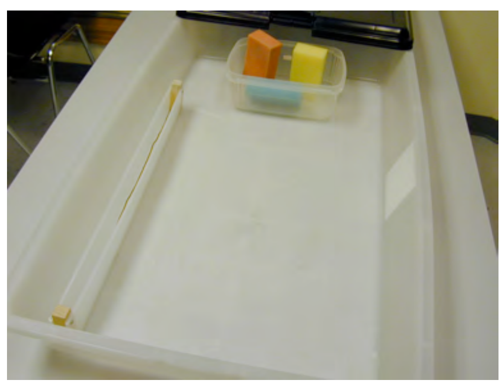
- *It would be good to reread the safety capsule about concrete in the present guide and in the student booklet.*
- *Adequately cover the work tables with newspaper, plastic or cardboard.*
- *A trowel or simple soup spoon may be used to fill the form.*
- *Once the form is filled, the concrete must be vibrated to release any air bubbles from the mix. To do so, simply shake the form while sliding it along the table.*
- *Excess concrete must be disposed of in the garbage*

Material

- 1 - 500mL beaker
- 1 - 150mL beaker
- 1 trowel (soup spoon)
- 1 wooden rod for stirring
- 1 plastic container to make the mix (approximate capacity 3 litres)
- 150mL cement powder
- Sand and gravel in sufficient quantities
- Water at room temperature

Notes about concrete curing

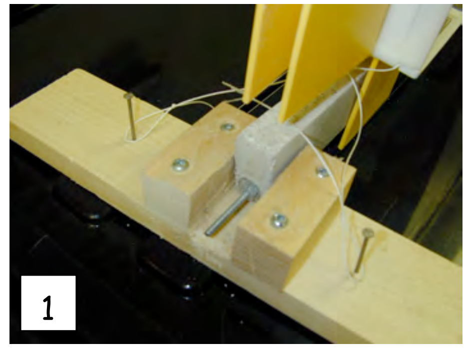
- Concrete curing must take place in a room temperature environment with a high degree of humidity.
- A plastic storage bin made to be slid under a bed suits the curing application perfectly. This type of bin will allow all the beams from one class to be stored together. A container filled with water or with wet sponges placed in the bin will ensure a very humid environment. Finally, this type of bin can be stacked one on top of the other (very practical when there are several classes).



Testing the beam (destructive resistance test)

Notes about installing the beam

- *Each team should install its beam under the supervision of the teacher or technician.*
- *Each extremity of the beam must rest on a wooden support. This way, the beam will stay in a vertical position (see photo 1)*
- *A « U » shaped iron bracket will allow the bucket which will be filled with sand to be hung (see photos 2 and 3).*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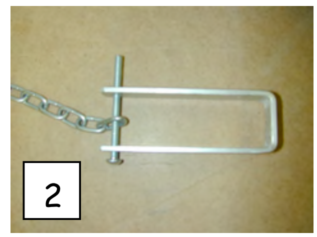
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Notes about the flexion measurement system

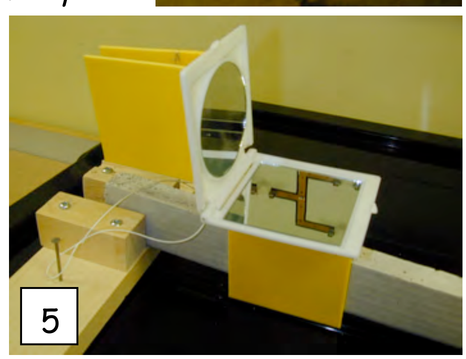
- *The mirror, placed on the beam, can be affixed to the beam by means of a band of polystyrene folded into a "U" shape. The mirror must be attached to the wooden support with string (see photo 5). This will protect it when the beam collapses.*
- *An inexpensive laser beam can be used for the test. The one shown in photo 4 cost $3.*
- *An 11X17 sheet of paper stuck to the wall can be used as a screen.*


4


3

Notes on the execution of the test

- *Clean sand should be used; otherwise the dust released into the class will soon make the air unbreathable. Sand for pool filters should do fine.*
- *The container to be used should have a known mass when filled with sand. This will allow you, when counting the number of containers, to better follow the evolution of the test. You could even periodically draw a point where the laser touches the screen, for example for every 5 containers full. A graph showing the deformation in relation to mass could be produced using the pattern formed. To do so, several geometrical considerations must however, be taken into account.*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- *If you want to accelerate the process, a minimum mass (for example 10 kg) could be used to keep only the best beams in the race. With your students, this way of proceeding may, however, discourage the teams whose beam is eliminated before the finals.*

Commision of inquiry regarding the collapse of your beam

Notes

- It is important that the students have access to the wreckage of their beam to complete this analysis
- To conclude the LES, the teacher could present the winning team's results to the rest of the class. At this time, the recipe used, the way the concrete was poured as well as the beam's plan could be broached.
- In a plenary session, it would be useful for all the concepts broached or deepened in this LES to be cited.

Suggested suppliers

- **For gravel**
  Réno-Dépôt
  «GET A GRIP» gravel to improve traction on ice

- **For «Coropast» corrugated plastic**
  Plastique Alto
  http://www.plastiquealto.com
  1-800-463-4710

- **For quick-set cement**
  MAPEI INC.
  http://www.mapei.com
  1-800 361-9309
  «Planipatch» Polymer modified finishing cement composite
  http://www.mapei.it/Referenze/Multimedia/Planipatch_TD_FC.pdf
  Profile sheet
  http://www.mapei.it/Referenze/Multimedia/Planipatch_MSDS.pdf

Website Bibliography

Concrete recipe (in French)
http://www.mapaq.gouv.qc.ca/Fr/Regions/chaudiereappalaches/journalvisionagricole/2003Decembre/0312_6.htm

Ratio of concrete and mortar (in French)
http://www.ideesmaison.com/Le-dosage-du-beton-et-du-mortier.html

Lafarge Cement (Research and innovation)
http://www.lafarge.com/wps/portal/3_2_5-Sciences_et_materiaux

Concrete without dust (in French)
http://www.lafarge.fr/lafarge/CONTENT_SHEET/20061020/10202006-press_cement_product-sensium-fr.wmv

Health dangers from cement (in French)
http://www.invs.sante.fr/surveillance/matgene/guide_matrice.pdf

Super plasticizer (additive for concrete) (in French)
http://www.lafarge.fr/12152006-group-superplastifiant-fr.wmv

Granular stacking (concrete formation) (in French)
http://www.lafarge.fr/lafarge/CONTENT_SHEET/20061215/12152006-group-empilement_granulaire-fr.wmv

« Super Traction» Granulate (granulometry passing through a sieve between 1-3 mm)
http://www.icemelter.ca/products/getagrip_super_e.php

Supplier for corrugated polypropylene (Coroplast) for forms
http://www.coroplast.com/
http://www.plastiquealto.com/english/products/products.htm

Geopolymer Institute (Chemistry of Portland cement)
http://www.geopolymer.org/science/portland-cement-chemistry-vs-geopolymer-chemistry