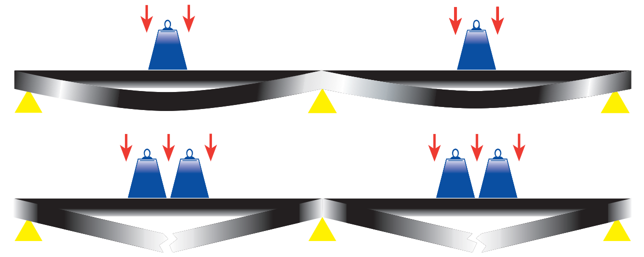
WHAT IS DUCTILITY?

Every reinforced concrete element, for example a beam, is composed of two materials; concrete and reinforcing steel.

Imagine a beam built of plain concrete (without reinforcing steel), supported at both ends and in the middle. If we load both spans, what happens?

- On initial loading, the beam deflects a little.
- In the second stage of loading, the beam suddenly collapses.

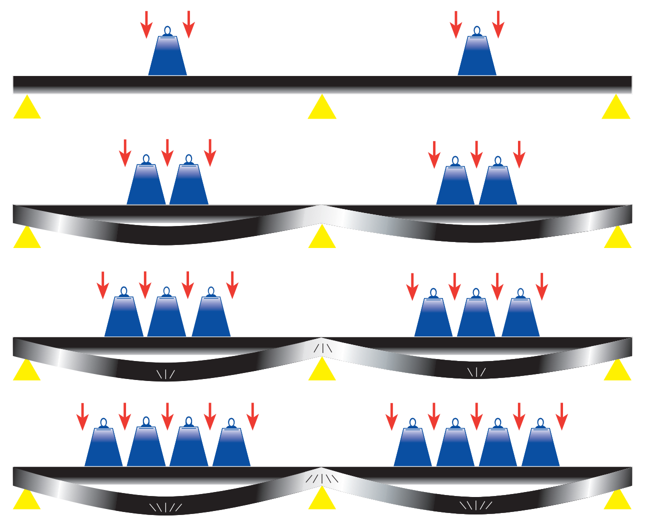


This happens because concrete is a brittle material with low ductility.

BRITTLE = NON DUCTILE

On the other hand, if the concrete is now reinforced with steel bars, and loaded in the same way as before, the outcome will be as follows:

- In the initial stage of loading, the beam deflects a little.
- In the second stage of loading, the beam continues to deform.
- In the third stage of loading, the beam deflects some more, and small cracks appear.
- In the fourth stage of loading the beam deflects even more and the cracking becomes more extensive.



"In general, the higher the steel ductility, the greater the ductility of the beam".

"The tensile ductility of steel is its ability to deform when loaded above its elastic limit without fracturing".

Concrete needs steel reinforcing bars to achieve ductility.

Reinforcing bars also need certain bond characteristics with concrete, in order to achieve the required composite behaviour with the concrete.

Celsa Reassure Grade 500C bars are designed to meet the bond requirements of BS 8110 Type 2 and EC2.

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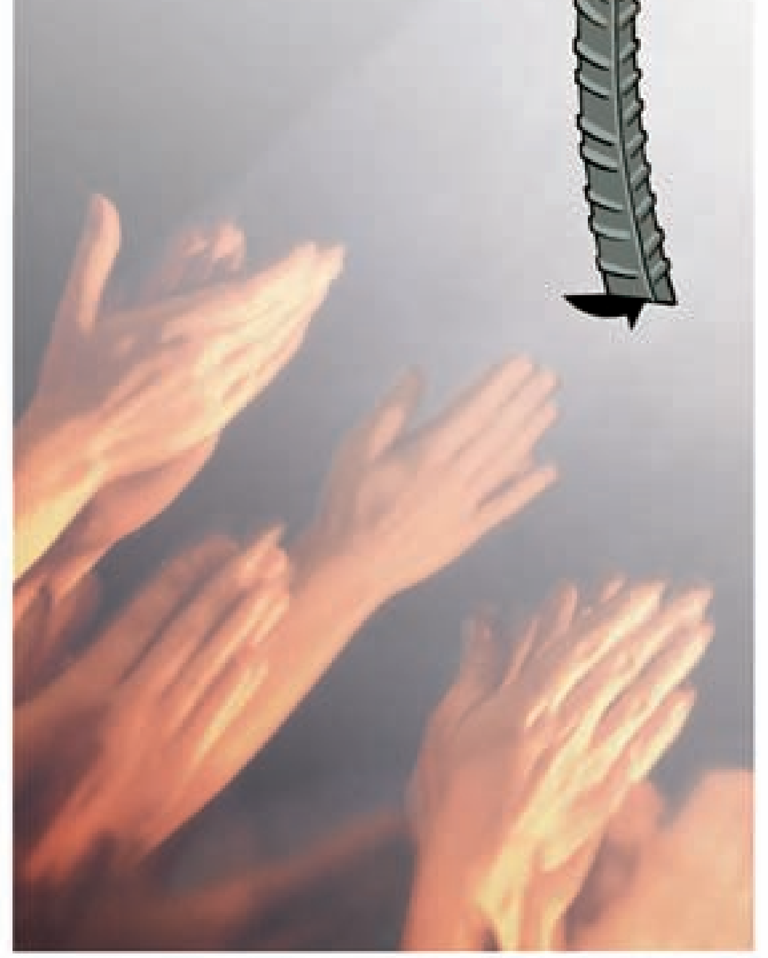
reassure

A round of applause for Ductility



Information sheet

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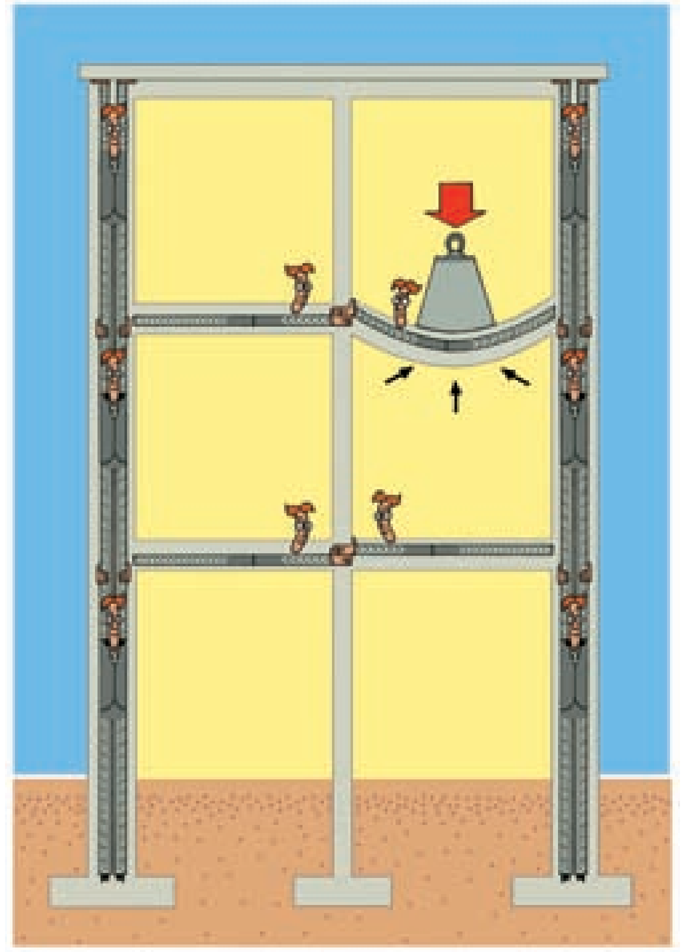
Ductility from Celsa Steel
A Guarantee of Safety

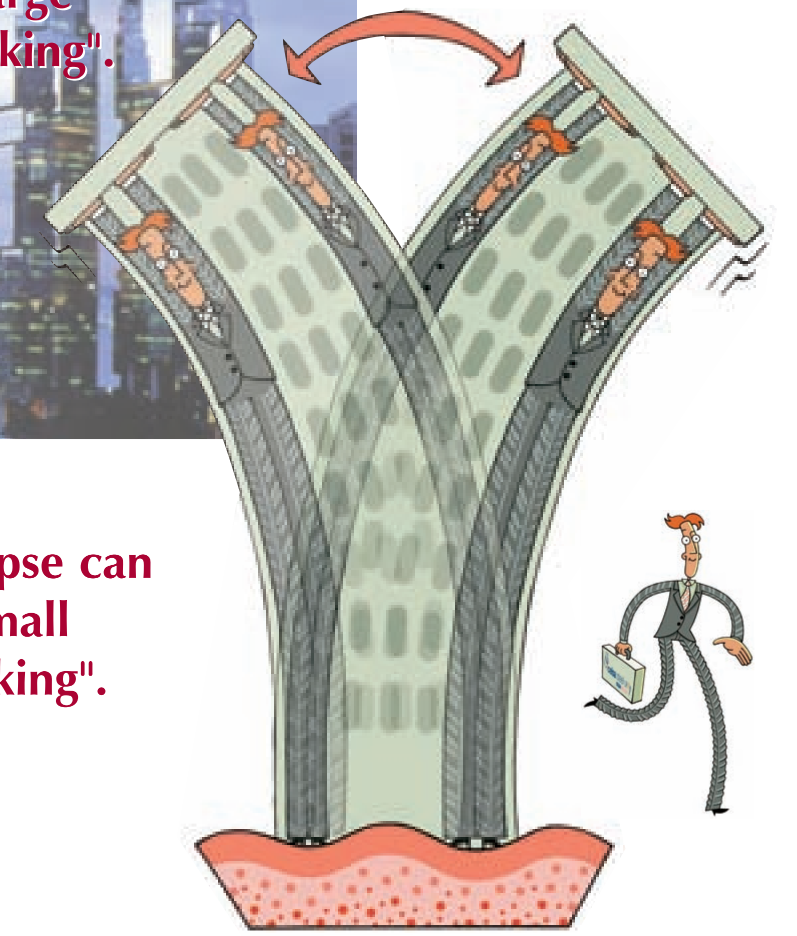


If we were in a building in an overload situation, for safety's sake, we would definitely prefer the structure to deform allowing us to evacuate, rather than to undergo a sudden collapse leaving us with no chance to escape in time.

Such overloads could be caused by:

- Explosion
- Impact damage
- Heavy loading on floors designed for light loading
- Flooding of roofs or floors
- Seismic activity
- Foundation movement due to the proximity of construction work, or problems with water infiltration, etc

"A ductile structure near collapse warns about its condition, through large deflections and extensive cracking".



"If the structure is brittle, collapse can occur with no warning, with small deflections and much less cracking".

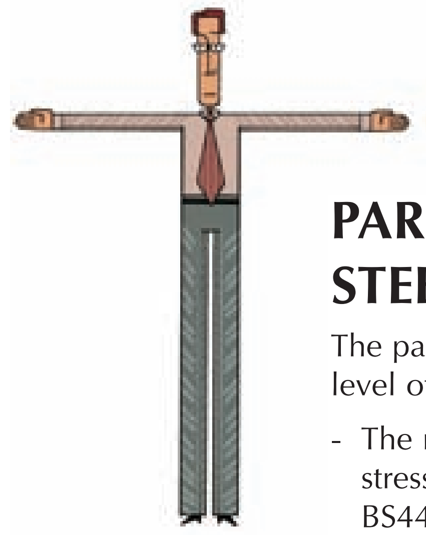
Ductility is Safety

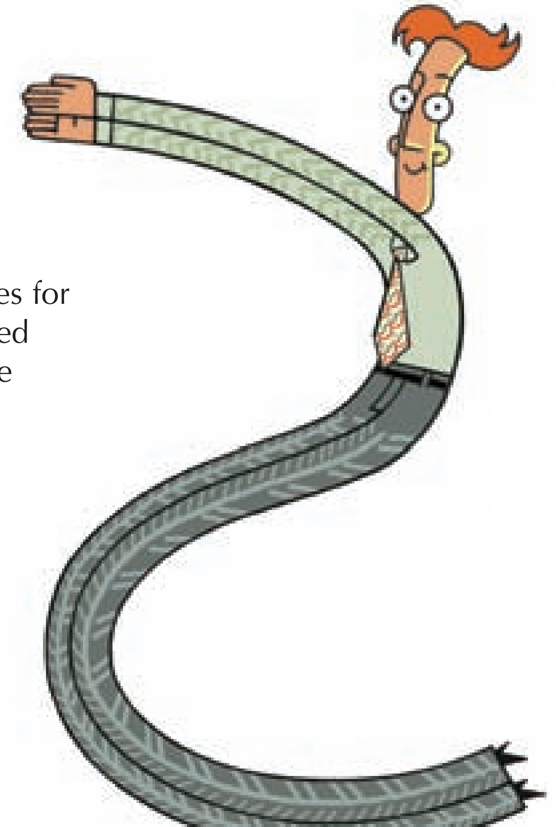
STEEL DUCTILITY

We have seen what is necessary to achieve ductility in a reinforced concrete beam. Now we shall see that there are some steels with relatively low ductility and others with much higher ductility levels. The behaviour of a reinforcing steel is mainly defined by its stress-strain curve, measured in a tensile test.

To obtain the stress-strain curve, we put a sample of the bar into a tensile testing machine and load the bar up until it fractures. The applied stress produces a resultant strain in the bar. If we plot the values of strain produced against the applied stress, we obtain the stress-strain curve for the steel.

In general terms there are two types of stress-strain curves for reinforcing steels, depending on the steel type; cold-rolled steel (Grade A) or hot-rolled steel (Grades B and C, more ductile steels).





PARAMETERS THAT DEFINE STEEL DUCTILITY

The parameters which have traditionally defined the level of ductility of a steel, are the following:

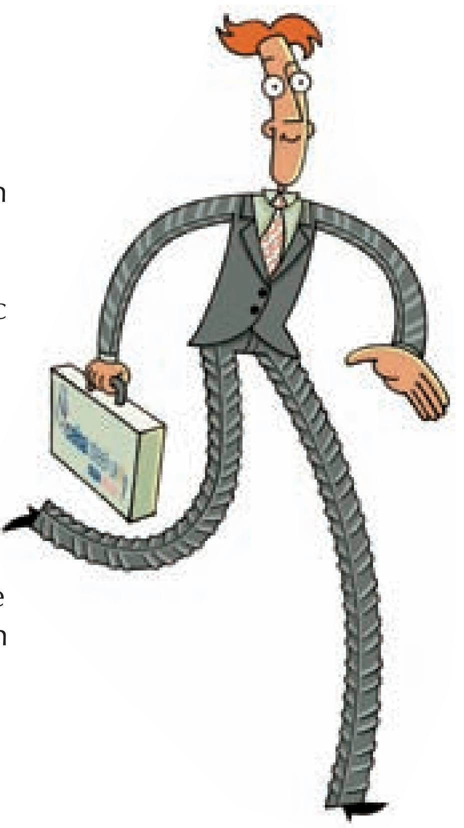
- The ratio between the ultimate tensile strength and the yield stress **(fs/fy)**. (The equivalent symbols used in the materials standards BS4449 and EN10080 are **Rm/Re**).
- Elongation to fracture, measured on a gauge length of 5 bar diameters, **(A5)**.

Now there is another parameter that defines elongation more accurately than **A5**. This is the uniform elongation, or elongation to maximum load, (Ɛu). (The equivalent symbol used in the materials standards BS 4449 and EN 10080 is **Agt**).

The higher the values of these parameters (**fs/fy**, and **Agt**) are, the greater the ductility of the steel.

TYPE OF STEEL		fs / fy	AGT	DUCTILITY GRADE
GRADE	500A	≥1.05	≥2.5%	LOW
GRADE	500B	≥1.08	≥5.0%	NORMAL
GRADE	500C	≥1.15-1.35	≥7.5%	HIGH

STRESS-STRAIN CURVE FOR A COLD-ROLLED STEEL (GRADE A)

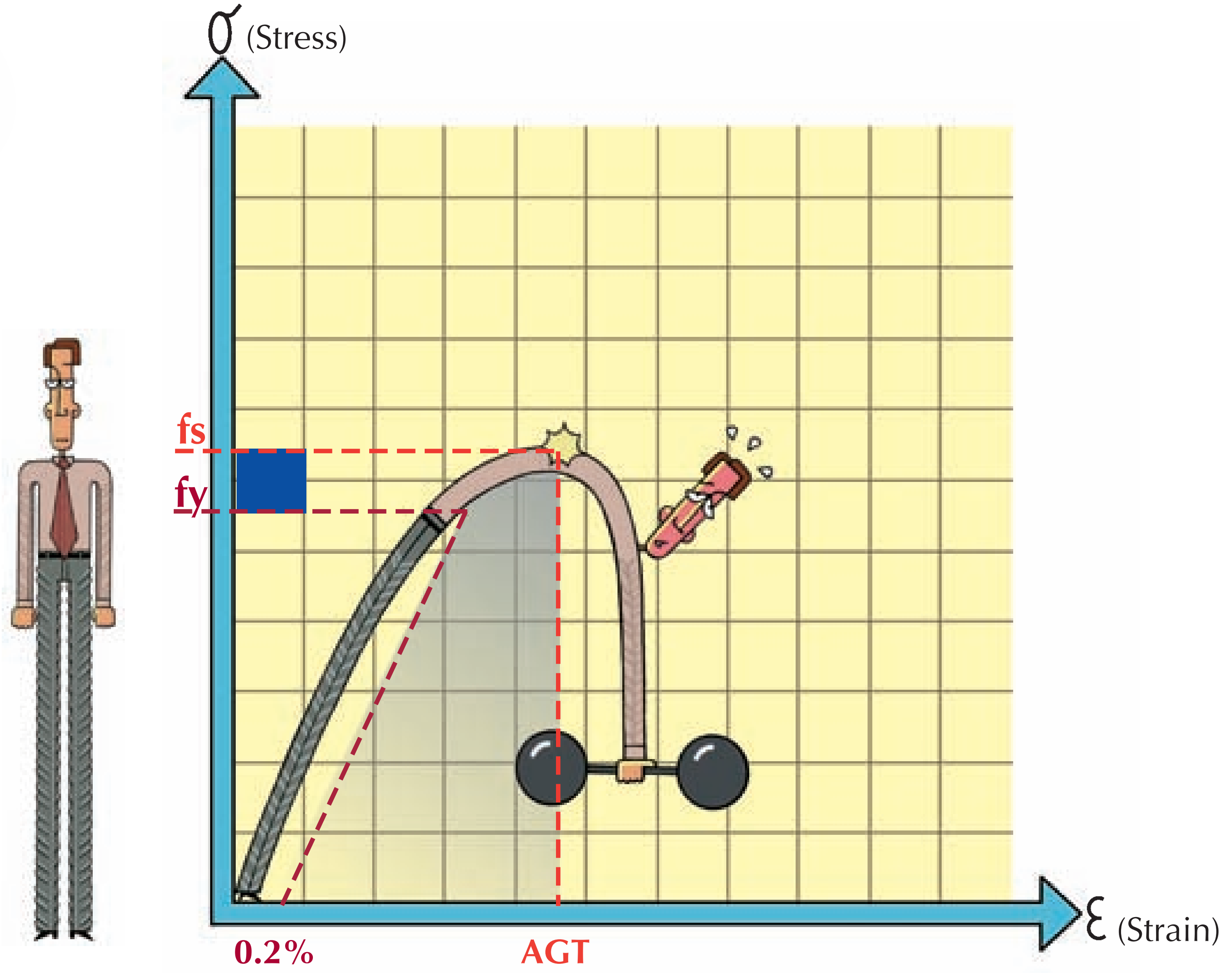


1. Elastic (linear) stage
In the initial stage of the tensile test, the steel behaviour is elastic (linear.) When a certain force F1 is applied, the resulting elongation of the bar sample is L1. If the force is doubled (2F1), the bar elongation also doubles (2L1). If the load is removed at this stage, the bar returns to its original length. This so-called elastic behaviour occurs until the yield stress (or elastic limit) of the steel is reached.

2. Plastic (non- linear) stage
Once the elastic limit is exceeded, the elongation increases significantly for small increments of the tensile load, until the maximum stress (ultimate tensile stress), **fs (Rm)**, is reached, after which the bar fractures. If the load is removed from the bar, the recovery of the sample is only that due to the elastic extension; i.e. the bar has undergone some permanent strain. During the tensile test, the cross-sectional area of the sample decreases, initially uniformly, then in a localised neck, reaching a minimum value at the point of fracture.

In a cold-rolled steel, the yield point is not clearly defined, and is close to the ultimate load. Both the **fs/fy (Rm/Re)** ratio and the Ɛu **(Agt)** are low.

LOW DUCTILITY



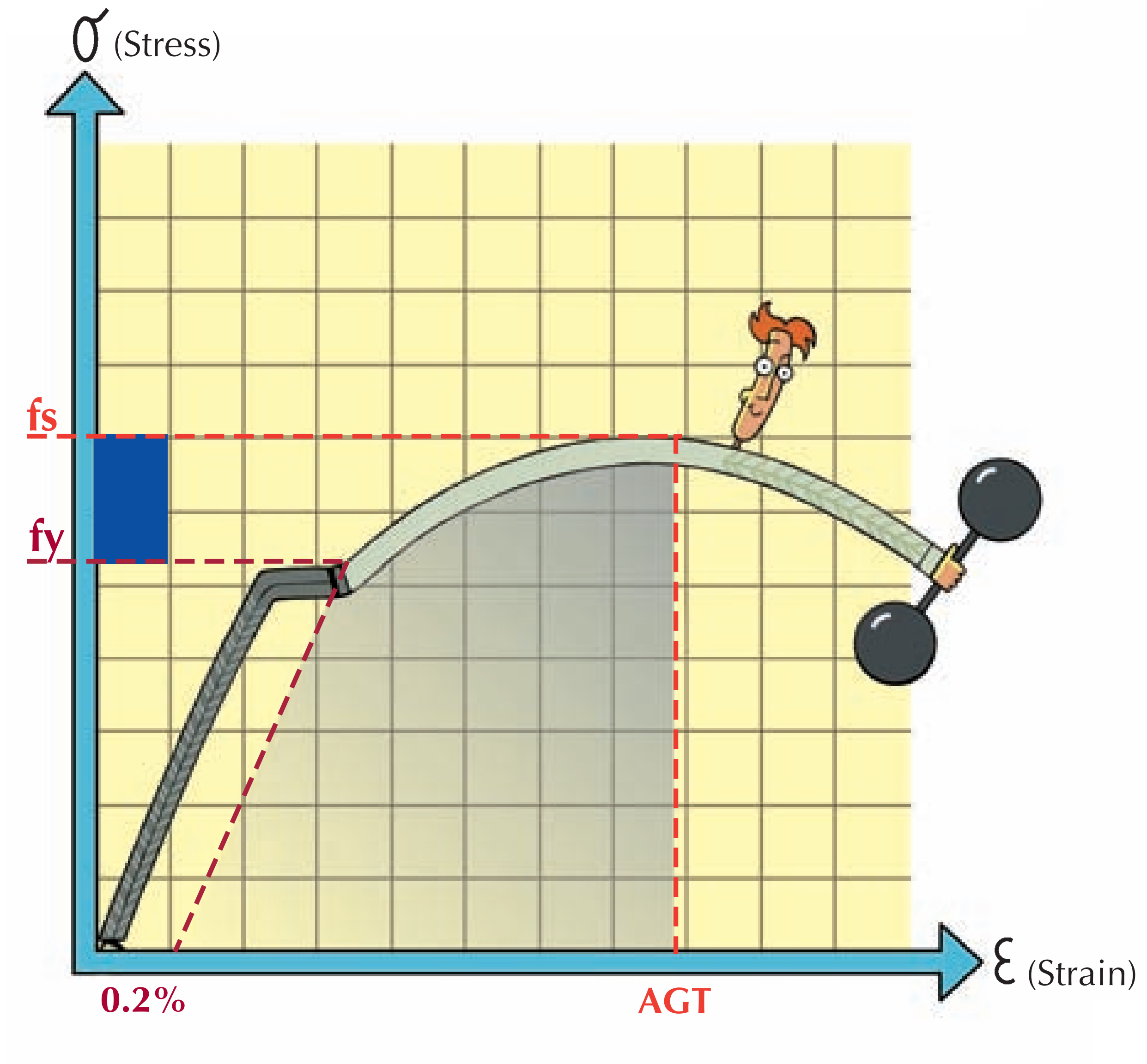
STRESS-STRAIN CURVE FOR A HOT - ROLLED STEEL (GRADES B AND C)

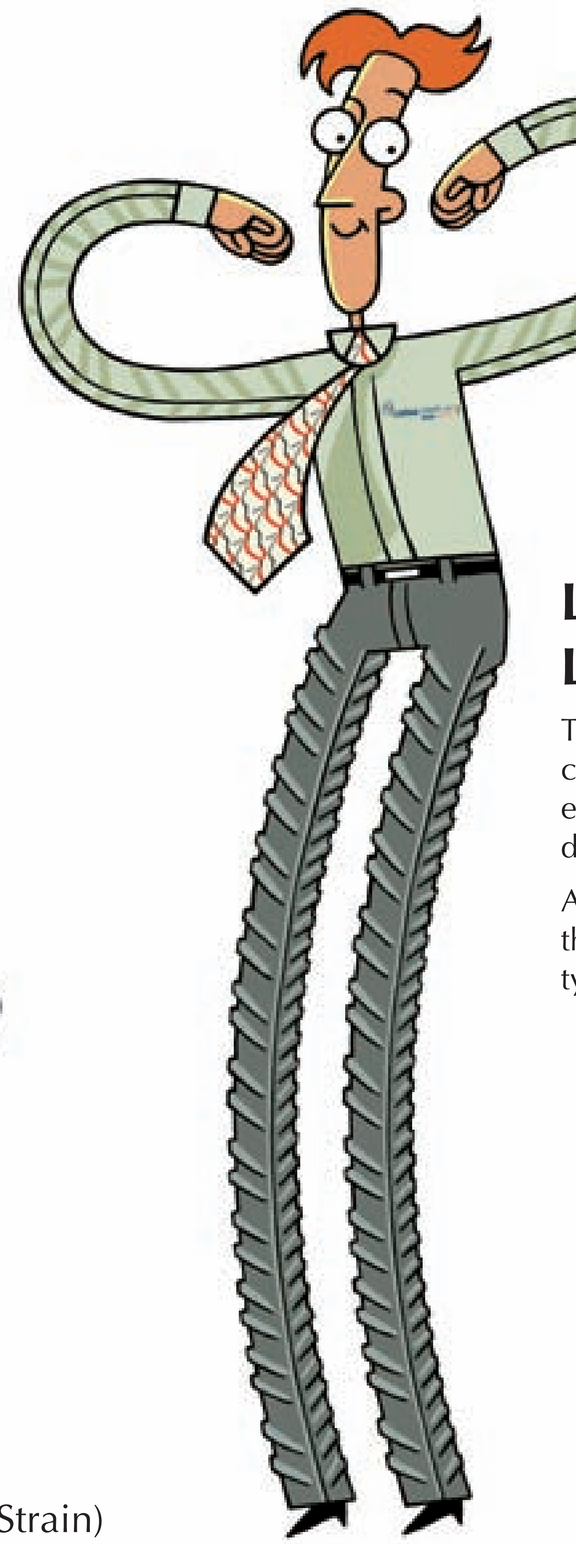
The stress-strain curve of a hot-rolled steel has an elastic range similar to that of a cold rolled steel. The main difference in the behaviour of the two types of steel comes after the elastic limit is reached.
In the case of hot rolled steels, once the yield stress is reached, the bar undergoes a certain amount of extension at nearly constant stress. This is reflected in the stress-strain curve by the "yield point elongation".

In this case, the yield point is clearly defined, unlike in the case of cold-rolled steel. After the yield point elongation, as load increases further, the strain increases much more than in cold-rolled steels. The ductility parameters **fs/fy (Rm/Re)** and Ɛu **(Agt)** for a hot-rolled steel are much greater than for a cold rolled steel.

Steel ductility is related to the area under the plastic portion of the stress-strain curve. This area represents the energy absorbed by the steel in plastic deformation prior to fracture.

NORMAL OR HIGH DUCTILITY





FATIGUE

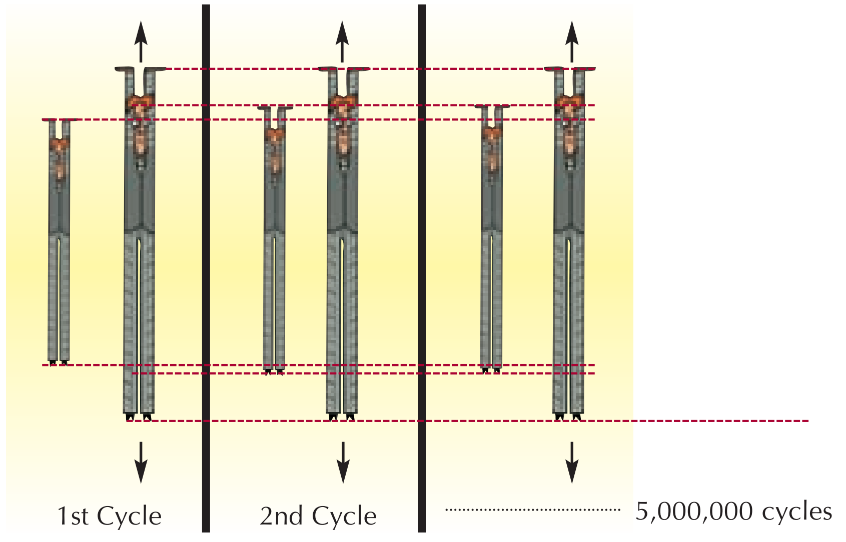
Fluctuating tensile loads can cause fracture of steel bars at stress levels below the yield stress.

This phenomenon is known as fatigue.

This effect can be important where there are significant dynamic loads, such as on railways, bridges etc.

In BS4449 to which the UK bridge code BS 5400 refers, steel has to survive at least 5,000,000 stress cycles under specified loading conditions.

Celsa Reassure Grade 500C fulfils these fatigue requirements in all sizes.



LOW CYCLE (TENSION & COMPRESSION) LOADING

This occurs when the stress in a steel bar is changed repetitively between tension and compression. The simplest example of this type of loading is to consider seismic effects. The behaviour of steel subjected to this variation in load pattern is very different to that of steel under fatigue loading conditions.

Alternating from tensile to compressive stress has a dramatic and destructive effect on the steel. Additional ductility greatly improves the capacity of a steel bar to resist this type of loading.