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INTRODUCTION

1.
Let us start with a brief introduction in order to help the student understand the objective of continuum mechanics.

2.
The first and foremost question one can ask the first time one hears about continuum mechanics is simply: what is it for? And once the answer has been given, one wonders how it has been possible to do without it for so long.

For the answer is very straightforward: "Continuum mechanics is for playing!" What could be more pleasant to hear?

As a matter of fact, with this aspect of physics, it will be possible for us to play with the most important elements of our lives and most of all understand the rules of the game and even set our own rules. Let us examine a few games in detail.

3.
Let us start by examining how air and wind can play with the mechanical engineer. Among other things, he designs and builds structures such as bridges whose official openings are welcome. Even if they have not entered a competition, engineers regularly strive to do better, to build larger and longer structures. Sometimes however, one forgets that a simple application of the rule of three is not sufficient to dimension structures correctly. External loads may disturb the system. Without reaching gale force, as is happening with increasing frequency, a moderate wind velocity with gusts reaching the right frequencies may excite a suspension bridge. It will then react like a swing and gradually reach higher and higher oscillation amplitudes. The phenomenon may be complex. The bridge deck undergoes torsion and flexion movements. Compared to the deck, the pillars seem to be relatively motionless; however the whole structure is affected. If the load is maintained over time at the right periodicity, the movement amplitudes may increase. Of course, since nothing lasts forever, our bridge will probably quit the game as the wind may not be to its taste.

4.
The water – bridge combination has a long history. At Cluny one page was written with a spaghetti bridge loaded with water in its center. Twenty or so spaghetti about 20cm long, properly assembled with glue, can make a 40cm-span truss bridge. The structure straight section is square with two upper chords and two lower chords. These lines are interconnected by small spaghetti triangulating the structure thus making it stiffer. At mid-span a load is gradually applied by pouring water into a recipient. A preliminary calculation resulted in assessing that the compressed upper chords marked in red will buckle in their center. The central connection node will rotate increasingly under the load thus resulting in the structure failure. The structure will have supported a mass of water over 2 kilograms then.

5.
A civil engineer must learn how to control soils. He has to know how to anchor properly the structures required for our development. Building important structures requires huge resources and long design and calculation hours. Each building stage has to be validated before going into production. There may be a variety of technologies implemented. The assembly and connection elements have to be made according to

processes previously defined and validated. The structures built may combine steel and reinforced concrete for instance. For a number of structures, it is necessary to contract with an engineering team consisting of various groups of skilled professionals. Of course all this has to be perfectly supervised and coordinated so as to reach the objective expected. In the case of the Millau Viaduct, it took a highly specialized engineering firm more than two years' design to dimension the structure correctly. Many records were broken then, however they will certainly be broken again in future achievements.

6.

Fire is a natural element with which an engineer should be able to play, even though he may not be able to control it at all times. In order to gain a better knowledge and therefore make better predictions about the behavior of structures during a fire, it is appropriate to make instrumented experiments. However it is difficult to work with small size models since thermal models are complicated to reduce. In this video provided by the Association for promoting steel construction training, one can see that it is possible to build buildings protected from the wind and rain thus creating a small city. Each building can then be used for experimentation. In order to closely reflect reality, the operation load has to be simulated with bags of sand placed on the floors. All the floors have to be loaded in this way if the test is to reflect reality. The dimensions show that the experiment is at scale 1:1. In order to proceed with the fire test, the shelter doors have to be shut so as to reduce the wind parameter effects. A 77 square meter apartment located on the fourth floor will then be fitted with flammable elements. Then striking a match will start the experiment. In the bottom left diagram, the temperature variation over time can be observed in one point of the structure. The fire is confined within the apartment by insulating partitions; however there will be side effects in the next door apartments. Various sensors are placed providing information on temperatures, displacement and deformation. Video cameras make it possible to visualize the development of flames inside the apartment. Infrared video cameras provide global temperature information at all points over time. For about an hour there is a gradual increase, then as the fuel is completely consumed, there is a decrease; the maximum temperature is about 1000 ° Celsius. Of course this is not simply arranged to have a fire filmed; fire departments have plenty of those. It is then necessary to assess the structure and examine its behavior during the test. When the steel beams are not protected from the fire, they are deformed and damage the building beyond recovery. Protections may reduce the damage. This type of test permits to compare calculations and measurements then readjust the model for future constructions.

7.

Let us now examine a simple application. We first build 9-meter long modules with 35-centimeter square section tubular beams. They are interconnected by welded spacers. Once a large number of modules have been made, they can be positioned vertically in groups of three at distances of 3 meters from each other. Several successive bundles are performed so as to increase the height. They are arranged in such a way that they make a square structure with 240 pillars around the edge. An inner square is made on the same principle. At the same time, using the triangulation method of the spaghetti bridge, Warren beams made of upper and lower chords are made. They will support plates and will become self-supporting elements. In the previous construction, they will interconnect the two squares. The connections between the pillars and the self-supporting elements are simply made with stands. Then it is possible to use the shuttering obtained to pour a concrete slab. When the operation is repeated at each level, a tower can be built without using an external crane, which makes it possible to reach staggering heights. After cladding the façade, the final result is one of the World Trade Center twin towers whose 110^{th} floor reached 410 meters.
Experimentation made it obvious that steel had to be protected against fire. However those experiments were dimensioned for an office fire, not for a fire fueled by thousands of liters of kerosene. And this very intense

fire finally destroyed the protections. They melted in the heat and fire thus becoming totally ineffective and the steel was in direct contact with the flames. It is to be noted that the tower supported perfectly the load caused by the impact, a load which is far lower than the effect of winds on the facades. The heating caused important deformations of the floor self-supporting elements in particular. The stand connections yielded and the floors collapsed one after another like a house of cards. Those floors were essential to the structure global stiffness. At the impact point, the pillars were no longer connected in the transverse direction and the buckling height increased. The upper floor load then contributed to the structure collapse.

8.

It is good to have toys to play, i.e. tools. As was seen earlier on, continuum mechanics is to make it possible to tackle very complex issues involving the behaviors of deformable solids, fluids and thermal actions.

And in order to interpret the physical phenomena involved, we will use mathematical modeling. Obviously the problem is complex and it is necessary to have the proper tools. That is the reason why we will use new concepts and notations. In other words it will be necessary to learn and command a new language. This should not discourage us. This is not the first time that we have had to learn a new language and many others before us did it. Some of them are dead but it has never been proved that the cause of their deaths was due to the learning of continuum mechanics. These tools are here to help us adopt a thorough approach.

9.

And rigor is of the essence if one is to avoid problems. Of course, when you deal with complex structures like the Millau Viaduct, you can expect difficulties, but you do not have to break records to meet problems.

Consider for instance a pent roof made of a truss beam supporting the roof purlins. The existing regulations make it possible to define the load taking into consideration the operation loads, the wind and snow. Weighting coefficients determine the loads to be examined thus making it possible to dimension the pieces, purlins and truss beam. However these calculations are often neglected for they are sometimes tedious and because experimentation gives successful results without too much fatigue.

However resting on one's laurels may not always be sufficient. As can be seen on this picture, a spill phenomenon over 10 cm occurred on one purlin just after completing the construction. Obviously the purlin section was wrong, or the steel used was not the one originally planned, or the connections of the purlins with the wall and the truss beam were not made properly, or the truss beam was undersized. As can be seen there may be plenty of causes and plenty of sources of error too. That is why it is so important to be rigorous and methodical.

10.

No one is expected to do the impossible and engineers should not be blamed for all the problems of this world.

If we come back to our bridge examples, it is easy to understand that there is a calculation method for practically all cases, at least predictable cases.

For some cases are difficult to predict. Very often man is the source of these cases.

But man is also unpredictable at times and it is impossible to imagine all the load cases our structures will have to support. But with the tools we have now, there are many load cases predicted that we can solve if we make the right assumptions or calculations.