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Analysis of Micro Slip between Fixed and Moving Body under Friction using ANSYS

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Abstract: It is well known that frictional phenomenon is a part of force resisting the relative motion of solid surfaces. When the force is not sufficient enough to move the body completely, there exists deformation on the body known as Micro Slip. The deformation at different positions on the body was calculated using ANSYS by giving variables- coefficient of friction, compressive force, and tensile force. The body is placed on the fixed body and compressive force is applied on top, tensile force is applied on side face simultaneously.

I. INTRODUCTION

Materials which we come across may be classified into elastic, plastic and rigid materials. An elastic material undergoes a deformation when subjected to an external loading such that the deformation disappears on the removal of the loading. A plastic material undergoes a continuous deformation during the period of loading and the deformation is permanent and the material does not regain its original dimensions on the removal of the loading. A rigid material does not undergo any deformation when subjected to an external loading. In practice no material is absolutely elastic nor plastic nor rigid. We attribute these properties when the deformations are within certain limits. Generally, we handle a member in its elastic range. Structural members are all generally designed so as to remain in the elastic condition under the action of the working loads.

A. Resistance to Deformation

A material when subjected to an external load system undergoes a deformation. Against this deformation the material will offer a resistance which tends to prevent the deformation. This resistance is offered by the material as long as the member is forced to remain in the deformed condition. This resistance is offered by the material by virtue f its strength. In the elastic stage, the resistance offered by the material is proportional to the deformation brought about on the material by the external loading. The material will have the ability to offer the necessary resistance when the deformation is within a certain limit. A loaded member remains in equilibrium when the resistance offered by the member against the deformation and the applied load are in equilibrium. When the member is incapable of offering the necessary resistance against the external forces, the deformation will continue leading to the failure of the member.

B. Types of Forces

A force is a push or pulls acting upon an object as a result of its interaction with another object. There are a variety of types of forces. Previously in this lesson, a variety of force types were placed into two broad category headings on the basis of whether the force resulted from the contact or non-contact of the two interacting objects.

1) Contact Forces Action-at-a-Distance Forces
2) Frictional Force Gravitational Force
3) Tension Force Electrical Force
4) Normal Force Magnetic Force
5) Air Resistance Force
6) Applied Force
7) Spring Force
8) Applied Force
9) Gravitational Force
10) Normal Force
11) Frictional Force
12) Air Resistance Force
13) Tension Force
14) Spring Force

An applied force is a force that is applied to an object by a person or another object. If a person is pushing a desk across the room, then there is an applied acting upon the object. The applied force is the force exerted on the desk by the person.

C. Gravity Force (also known as Weight).

The force of gravity is the force with which the earth, moon, or other massively large object attracts another object towards itself. By definition, this is the weight of the object. All objects upon earth experience a force of gravity that is directed "downward" towards the center of the earth. The force of gravity on earth is always equal to the weight of the object as found by the equation:
Fgrav = m * g
where g = 9.8 N/kg (on Earth)
and m = mass (in kg)

D. Normal Force (F_{norm})

The normal force is the support force exerted upon an object that is in contact with another stable object. For example, if a book is resting upon a surface, then the surface is exerting an upward force upon the book in order to support the weight of the book. On occasions, a normal force is exerted horizontally between two objects that are in contact with each other. For instance, if a person leans against a wall, the wall pushes horizontally on the person.

E. Friction Force (F_{frict})

The friction force is the force exerted by a surface as an object moves across it or makes an effort to move across it. There are at least two types of friction force - sliding and static friction. Thought it is not always the case, the friction force often opposes the motion of an object. For example, if a book slides across the surface of a desk, then the desk exerts a friction force in the opposite direction of its motion. Friction results from the two surfaces being pressed together closely, causing intermolecular attractive forces between molecules of different surfaces. As such, friction depends upon the nature of the two surfaces and upon the degree to which they are pressed together. The maximum amount of friction force that a surface can exert upon an object can be calculated using the formula below:
$F_{frict} = \mu \cdot F_{norm}$

F. Sliding Versus Static Friction

The friction force is the force exerted by a surface as an object moves across it or tries to move across it. For the purpose of our study of physics at The Physics Classroom, there are two types of friction force - static friction and sliding friction. Sliding friction results when an object slides across a surface. As an example, consider pushing a box across a floor. The floor surface resists the movement of the box. We often say that the floor exerts a friction force upon the box. This is an example of a sliding friction force since it results from the sliding motion of the box. If a car slams on its brakes and skids to a stop (without antilock brakes), there is a sliding friction force exerted upon the car tires by the roadway surface. This friction force is also a sliding friction force because the car is sliding across the road surface. Sliding friction forces can be calculated from knowledge of the coefficient of friction and the normal force exerted upon the object by the surface it is sliding across. The formula is:
Sliding $F_{frict} = \mu \cdot F_{norm}$
The symbol represents the coefficient of sliding friction between the two surfaces. The coefficient value is dependent primarily upon the nature of the surfaces that are in contact with each other. For most surface combinations, the friction coefficients show little dependence upon other variables such as area of contact, temperature, etc. Values of have been experimentally determined for a variety of surface combinations and are often tabulated in technical manuals and handbooks. The values of μ provide a measure of the relative amount of adhesion or attraction of the two surfaces for each other. The more that surface molecules tend to adhere to each other, the greater the coefficient values and the greater the friction force. Friction forces can also exist when the two surfaces are not sliding across each other. Such friction forces are referred to as static friction. Static friction results when the surfaces of two objects are at rest relative to one another and a force exists on one of the objects to set it into motion relative to the other object. Suppose you were to push with 5- Newton of force on a large box to move it across the floor. The box might remain in place. A static friction force exists between the surfaces of the floor and the box to prevent the box from being set into motion. The static friction force balances the force that you exert on the box such that the stationary box remains at rest. When exerting 5 Newton of applied force on the box, the static friction force has a magnitude of 5 Newton. Suppose that you were to push with 25 Newton of force on the large box and the box were to still remain in place.

Static friction now has a magnitude of 25 Newton. The amount of static friction resulting from the adhesion of any two surfaces has an upper limit. In this case, the static friction force spans the range from 0 Newton (if there is no force upon the box) to 25 Newton (if you push on the box with 25 Newton of force). This relationship is often expressed as follows:

$F_{frict\text{-}static} \leq \mu_{frict\text{-}static} \bullet F_{norm}$

The symbol μfrict-static represents the coefficient of static friction between the two surfaces. Like the coefficient of sliding friction, this coefficient is dependent upon the types of surfaces that are attempting to move across each other. In general, values of static friction coefficients are greater than the values of sliding friction coefficients for the same two surfaces. Thus, it typically takes more force to budge an object into motion than it does to maintain the motion once it has been started. The meaning of each of these forces listed in the table above will have to be thoroughly understood to be successful during this unit. Ultimately, you must be able to read a verbal description of a physical situation and know enough about these forces to recognize their presence (or absence) and to construct a free-body diagram that illustrates their relative magnitude and direction.

G. Friction

Friction is the force resisting the relative motion of solid surfaces, fluid layers, and material elements sliding against each other. There are several types of friction:

Dry friction resists relative lateral motion of two solid surfaces in contact. Dry friction is subdivided into static friction between non-moving surfaces, and kinetic friction between moving surfaces.

Fluid friction describes the friction between layers within a viscous fluid that are moving relative to each other.

Lubricated friction is a case of fluid friction where a fluid separates two solid surfaces.

Skin friction is a component of drag, the force resisting the motion of a solid body through a fluid.

Internal friction is the force resisting motion between the elements making up a solid material while it undergoes deformation. When surfaces in contact move relative to each other, the friction between the two surfaces converts kinetic energy into heat. This property can have dramatic consequences, as illustrated by the use of friction created by rubbing pieces of wood together to start a fire. Kinetic energy is converted to heat whenever motion with friction occurs, for example when a viscous fluid is stirred. Another important consequence of many types of friction can be wear, which may lead to performance degradation and/or damage to components. Friction is a component of the science of tribology Friction is not a fundamental force but occurs because of the electromagnetic forces between charged particles which constitute the surfaces in contact. Because of the complexity of these interactions, friction cannot be calculated from first principles, but instead must be found empirically.

H. Laws of Dry Friction

The elementary properties of sliding (kinetic) friction were discovered by experiment in the 15th to 18th centuries and were expressed as three empirical laws

1) *Amontons' First Law:* The force of friction is directly proportional to the applied load.
2) *Amontons' Second Law:* The force of friction is independent of the apparent area of contact.
3) *Coulomb's Law of Friction:* Kinetic friction is independent of the sliding velocity.

Amontons' 2nd Law is an idealization assuming perfectly rigid and inelastic materials.

I. Dry Friction

Dry friction resists relative lateral motion of two solid surfaces in contact. The two regimes of dry friction are 'static friction' between non-moving surfaces, and kinetic friction (sometimes called sliding friction or dynamic friction) between moving surfaces. Coulomb friction, named after Charles-Augustin de Coulomb, is an approximate model used to calculate the force of dry friction where is the force. It is parallel to the surface, in a direction opposite to the net applied force. It is the coefficient of friction, which is an empirical property of the contacting materials, is the normal force exerted by each surface on the other, directed perpendicular (normal) to the surface. The Coulomb friction may take any value from zero up to , and the direction of the frictional force against a surface is opposite to the motion that surface would experience in the absence of friction. Thus, in the static case, the frictional force is exactly what it must be in order to prevent motion between the surfaces; it balances the net force tending to cause such motion. In this case, rather than providing an estimate of the actual frictional force, the Coulomb approximation provides a threshold value for this force, above which motion would commence. This maximum force is known as traction. The force of friction is always exerted in a direction that opposes movement (for kinetic friction) or potential movement (for static friction) between the two surfaces.

For example, a curling stone sliding along the ice experiences a kinetic force slowing it down. For an example of potential movement, the drive wheels of an accelerating car experience a frictional force pointing forward; if they did not, the wheels would spin, and the rubber would slide backwards along the pavement. Note that it is not the direction of movement of the vehicle they oppose, it is the direction of (potential) sliding between tire and road.

J. Normal Force

The normal force is defined as the net force compressing two parallel surfaces together; and its direction is perpendicular to the surfaces. In the simple case of a mass resting on a horizontal surface, the only component of the normal force is the force due to gravity, where. In this case, the magnitude of the friction force is the product of the mass of the object, the acceleration due to gravity, and the coefficient of friction.

However, the coefficient of friction is not a function of mass or volume; it depends only on the material. For instance, a large aluminum block has the same coefficient of friction as a small aluminum block. However, the magnitude of the friction force itself depends on the normal force, and hence the mass of the block. If an object is on a level surface and the force tending to cause it to slide is horizontal, the normal force between the object and the surface is just its weight, which is equal to its mass multiplied by the acceleration due to earth's gravity, g. If the object is on a tilted surface such as an inclined plane, the normal force is less, because less of the force of gravity is perpendicular to the face of the plane. Therefore, the normal force, and ultimately the frictional force, is determined using vector analysis, usually via a free body diagram. Depending on the situation, the calculation of the normal force may include forces other than gravity.

K. Coefficient of Friction

The coefficient of friction (COF), often symbolized by the Greek letter μ, is a dimensionless scalar value Free-body diagram for a block on a ramp. Arrows are vectors indicating directions and magnitudes of forces. N is the normal force, mg is the force of gravity, and Ff is the force of friction, which describes the ratio of the force of friction between two bodies and the force pressing them together.

The coefficient of friction depends on the materials used; for example, ice on steel has a low coefficient of friction, while rubber on pavement has a high coefficient of friction. Coefficients of friction range from near zero to greater than one – under good conditions, a tire on concrete may have a coefficient of friction of. For surfaces at rest relative to each other, where is the coefficient of static friction. This is usually larger than its kinetic counterpart. For surfaces in relative motion, where is the coefficient of kinetic friction. The Coulomb friction is equal to, and the frictional force on each surface is exerted in the direction opposite to its motion relative to the other surface.

It was Arthur-Jules Morin who introduced the term and demonstrated the utility of the coefficient of friction. The coefficient of friction is an empirical measurement – it has to be measured experimentally and cannot be found through calculations. Rougher surfaces tend to have higher effective values. Both static and kinetic coefficients of friction depend on the pair of surfaces in contact; for a given pair of surfaces, the coefficient of static friction is usually larger than that of kinetic friction; in some sets the two coefficients are equal, such as teflon-on-teflon. Most dry materials in combination have friction coefficient values between 0.3 and 0.6. Values outside this range are rarer, but teflon, for example, can have a coefficient as low as 0.04. A value of zero would mean no friction at all, an elusive property – even magnetic levitation vehicles have drag. Rubber in contact with other surfaces can yield friction coefficients from 1 to 2. Occasionally it is maintained that μ is always < 1, but this is not true. While in most relevant applications $\mu < 1$, a value above 1 merely implies that the force required to slide an object along the surface is greater than the normal force of the surface on the object.

For example, silicone rubber or acrylic rubber-coated surfaces have a coefficient of friction that can be substantially larger than 1. While it is often stated that the COF is a "material property," it is better categorized as a "system property." Unlike true material properties (such as conductivity, dielectric constant, yield strength), the COF for any two materials depends on system variables like temperature, velocity, atmosphere and also what are now popularly described as aging and deaging times; as well as on geometric properties of the interface between the materials. For example, a copper pin sliding against a thick copper plate can have a COF that varies from 0.6 at low speeds (metal sliding against metal) to below 0.2 at high speeds when the copper surface begins to melt due to frictional heating.

The latter speed, of course, does not determine the COF uniquely; if the pin diameter is increased so that the frictional heating is removed rapidly, the temperature drops, the pin remains solid and the COF rise s to that of a 'low speed' test.

L. Angle of Friction

For certain applications it is more useful to define static friction in terms of the maximum angle before which one of the items will begin sliding. This is called the angle of friction or friction angle. It is defined as: where θ is the angle from vertical and μs is the static coefficient of friction between the objects. This formula can also be used to calculate μs from empirical measurements of the friction angle. Friction at the atomic level

Determining the forces required to move atoms past each other is a challenge in designing nano-machines. In 2008 scientists for the first time were able to move a single atom across a surface, and measure the forces required. Using ultrahigh vacuum and nearly-zero temperature (5 K), a modified atomic force microscope was used to drag a cobalt atom, and a carbon monoxide molecule, across surfaces of copper and platinum.

Limitations of the Coulomb model The Coulomb approximation mathematically follows from the assumptions that surfaces are in atomically close contact only over a small fraction of their overall area, that this contact area is proportional to the normal force (until saturation, which takes place when all area is in atomic contact), and that frictional force is proportional to the applied normal force, independently of the contact area (you can see the experiments on friction from Leonardo Da Vinci). Such reasoning aside, however, the approximation is fundamentally an empirical construction. It is a rule of thumb describing the approximate outcome of an extremely complicated physical interaction. The strength of the approximation is its simplicity and versatility – though in general the relationship between normal force and frictional force is not exactly linear (and so the frictional force is not entirely independent of the contact area of the surfaces), the Coulomb approximation is an adequate representation of friction for the analysis of many physical systems. When the surfaces are conjoined, Coulomb friction becomes a very poor approximation (for example, adhesive tape resists sliding even when there is no normal force, or a negative normal force). In this case, the frictional force may depend strongly on the area of contact. Some drag racing tires are adhesive in this way. However, despite the complexity of the fundamental physics behind friction, the relationships are accurate enough to be useful in many applications.

M. Fluid Friction

Fluid friction occurs between layers within a fluid that are moving relative to each other. This internal resistance to flow is described by viscosity. In everyday terms viscosity is "thickness". Thus, water is "thin", having a lower viscosity, while honey is "thick", having a higher viscosity. Put simply, the less viscous the fluid is, the greater its ease of movement. All real fluids (except super fluids) have some resistance to stress and therefore are viscous, but a fluid which has no resistance to shear stress is known as an ideal fluid or inviscid fluid.

N. Lubricated Friction

Lubricated friction is a case of fluid friction where a fluid separates two solid surfaces. Lubrication is a technique employed to reduce wear of one or both surfaces in close proximity moving relative to each another by interposing a substance called a lubricant between the surfaces. In most cases the applied load is carried by pressure generated within the fluid due to the frictional viscous resistance to motion of the lubricating fluid between the surfaces. Adequate lubrication allows smooth continuous operation of equipment, with only mild wear, and without excessive stresses or seizures at bearings. When lubrication breaks down, metal or other components can rub destructively over each other, causing heat and possibly damage or failure.

O. Skin Friction

Skin friction arises from the friction of the fluid against the "skin" of the object that is moving through it. Skin friction arises from the interaction between the fluid and the skin of the body, and is directly related to the area of the surface of the body that is in contact with the fluid. Skin friction follows the drag equation and rises with the square of the velocity. Skin friction is caused by viscous drag in the boundary layer around the object. There are two ways to decrease skin friction: the first is to shape the moving body so that smooth flow is possible, like an airfoil. The second method is to decrease the length and cross-section of the moving object as much as is practicable.

P. Internal Friction

Internal friction is the force resisting motion between the elements making up a solid material while it undergoes plastic deformation. Plastic deformation in solids is an irreversible change in the internal molecular structure of an object. This change may be due to either (or both) an applied force or a change in temperature. The change of an object's shape is called strain. The force causing it is called stress. Stress does not necessarily cause permanent change.

As deformation occurs, internal forces oppose the applied force. If the applied stress is not too large these opposing forces may completely resist the applied force, allowing the object to assume a new equilibrium state and to return to its original shape when the force is removed. This is what is known in the literature as elastic deformation (or elasticity). Larger forces in excess of the elastic limit may cause a permanent (irreversible) deformation of the object. This is what is known as plastic deformation.

Q. Rolling Resistance

Rolling resistance is the force that resists the rolling of a wheel or other circular object along a surface caused by deformations in the object and/or surface. Generally the force of rolling resistance is less than that associated with kinetic friction. Typical values for the coefficient of rolling resistance are 0.001. One of the most common examples of rolling resistance is the movement of motor vehicle tires on a road, a process which generates heat and sound as by-products.

R. Triboelectric Effect

Rubbing dissimilar materials against one another can cause a build-up of electrostatic charge, which can be hazardous if flammable gases or vapours are present. When the static build-up discharges, explosions can be caused by ignition of the flammable mixture.

S. Belt Friction

Belt friction is a physical property observed from the forces acting on a belt wrapped around a pulley, when one end is being pulled. The resulting tension, which acts on both ends of the belt, can be modeled by the belt friction equation. In practice, the theoretical tension acting on the belt or rope calculated by the belt friction equation can be compared to the maximum tension the belt can support. This helps a designer of such a rig to know how many times the belt or rope must be wrapped around the pulley to prevent it from slipping. Mountain climbers and sailing crews demonstrate a standard knowledge of belt friction when accomplishing basic tasks.

T. Reducing Friction

1) *Devices:* Devices such as wheels, ball bearings, roller bearings, and air cushion or other types of fluid bearings can change sliding friction into a much smaller type of rolling friction. Many thermoplastic materials such as nylon, HDPE and PTFE are commonly used in low friction bearings. They are especially useful because the coefficient of friction falls with increasing imposed load. For improved wear resistance, very high molecular weight grades are usually specified for heavy duty or critical bearings.
2) *Lubricants:* A common way to reduce friction is by using a lubricant, such as oil, water, or grease, which is placed between the two surfaces, often dramatically lessening the coefficient of friction. The science of friction and lubrication is called tribology. Lubricant technology is when lubricants are mixed with the application of science, especially to industrial or commercial objectives. Superlubricity, a recently-discovered effect, has been observed in graphite: it is the substantial decrease of friction between two sliding objects, approaching zero levels. A very small amount of frictional energy would still be dissipated. Lubricants to overcome friction need not always be thin, turbulent fluids or powdery solids such as graphite and talc; acoustic lubrication actually uses sound as a lubricant. Another way to reduce friction between two parts is to superimpose micro-scale vibration to one of the parts. This can be sinusoidal vibration as used in ultrasound-assisted cutting or vibration noise, known as dither.
3) *Energy of Friction:* According to the law of conservation of energy, no energy is destroyed due to friction, though it may be lost to the system of concern. Energy is transformed from other forms into heat. A sliding hockey puck comes to rest because friction converts its kinetic energy into heat. Since heat quickly dissipates, many early philosophers, including Aristotle, wrongly concluded that moving objects lose energy without a driving force. Energy lost to a system as a result of friction is a classic example of thermodynamic irreversibility.
4) *Work of Friction:* In the reference frame of the interface between two surfaces, static friction does not work, because there is never displacement between the surfaces. In the same reference frame, kinetic friction is always in the direction opposite the motion, and does negative work. However, friction can do positive work in certain frames of reference. One can see this by placing a heavy box on a rug, then pulling on the rug quickly. In this case, the box slides backwards relative to the rug, but moves forward relative to the frame of reference in which the floor is stationary. Thus, the kinetic friction between the box and rug accelerates the box in the same direction that the box moves, doing positive work. The work done by friction can translate into deformation, wear, and heat that can affect the contact surface properties (even the coefficient of friction between the

surfaces). This can be beneficial as in polishing. The work of friction is used to mix and join materials such as in the process of friction welding. Excessive erosion or wear of mating surfaces occur when work due frictional forces rise to unacceptable levels. Harder corrosion particles caught between mating surfaces (fretting) exacerbates wear of frictional forces. As surfaces are worn by work due to friction, fit and surface finish of an object may degrade until it no longer functions properly.

5) *Applications:* Friction is an important factor in many engineering disciplines.
6) *Transportation:* Rail adhesion refers to the grip wheels of a train have on the rails. Road slipperiness is an important design and safety factor for automobiles. Split friction is a particularly dangerous condition arising due to varying friction on either side of a car. Road texture affects the interaction of tires and the driving surface.

II. SIMULATION ANALYSIS

Simulation is the imitation of the operation of a real-world process or system over time. The act of simulating something first requires that a model be developed; this model represents the key characteristics or behaviours of the selected physical or abstract system or process. The model represents the system itself, whereas the simulation represents the operation of the system over time.

Simulation is used in many contexts, such as simulation of technology for performance optimization, safety engineering, testing, training, education, and video games. Training simulators include flight simulators for training aircraft pilots to provide them with a lifelike experience. Simulation is also used with scientific modelling of natural systems or human systems to gain insight into their functioning. Simulation can be used to show the eventual real effects of alternative conditions and courses of action. Simulation is also used when the real system cannot be engaged, because it may not be accessible, or it may be dangerous or unacceptable to engage, or it is being designed but not yet built, or it may simply not exist.

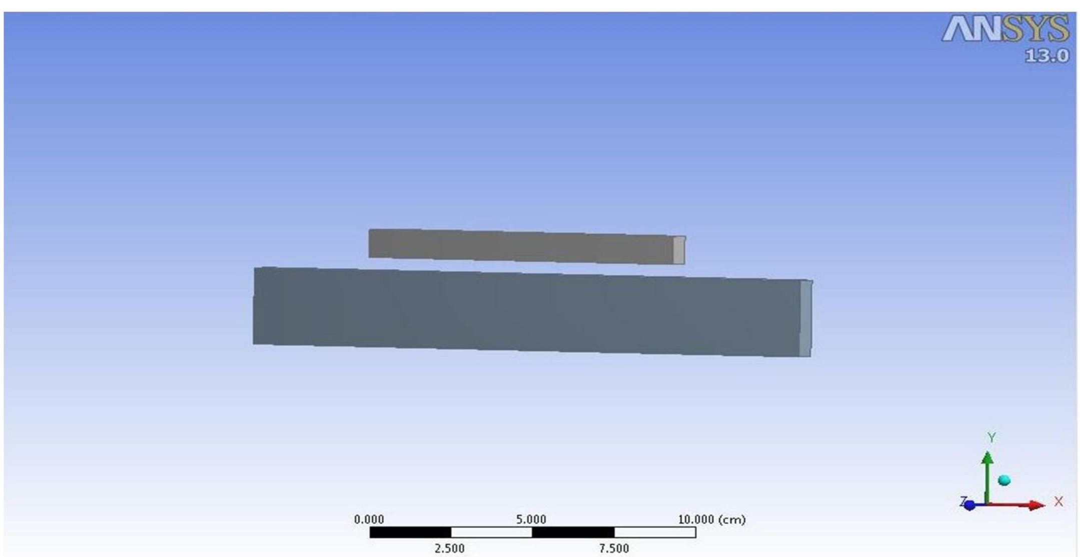
Key issues in simulation include acquisition of valid source information about the relevant selection of key characteristics and behaviours, the use of simplifying approximations and assumptions within the simulation, and fidelity and validity of the simulation outcomes.

A. *Simulation Using ANSYS*

Using ANSYS RELEASE 13.0 workbench the data has been simulated. In the Workbench we have used the STATIC STRUCTURAL toolbox in simulating the academic project data.

B. *BAR*

Engineering data cell is used to define or access material models for use in an analysis as structural steel. Geometry cell is used to import, create, edit or update the geometry model used for analysis. A bar of length 10cms, breadth 1cm, height 1cm is created using the geometry cell and a surface of dimensions more than the bar has been created.



The Model cell in the Mechanical application analysis systems or the Mechanical Model component system is associated with the Model branch in the Mechanical application and affects the definition of the geometry, coordinate systems, connections and mesh branches of the model definition.

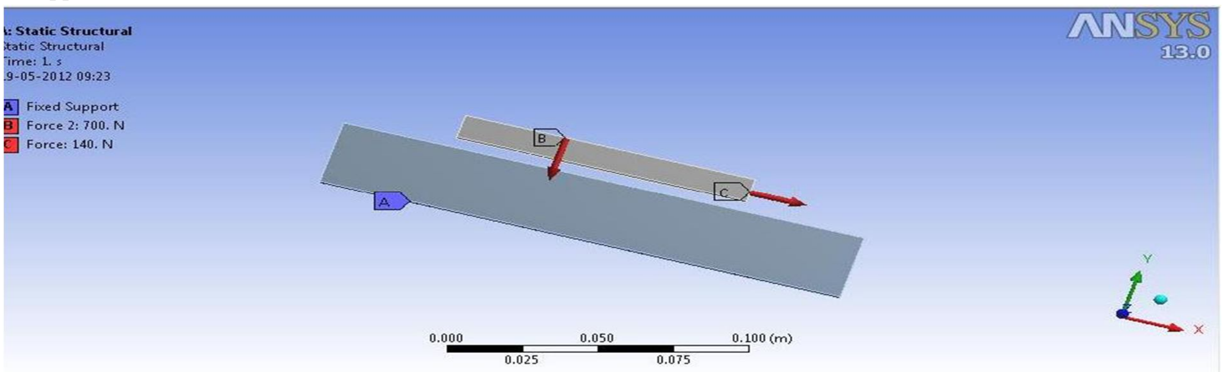
C. Mesh
The meshing was done using the mesh option.

D. Fixed Support
The surface bar below the 10cms bar has been fixed using the fixed support option in supports.

E. Compressive Force
A Compressive force was applied on the 10cms bar which varies from 300-800N.

F. Tensile Force
A Tensile force was applied on the 10cms bar which varies from 0N to its corresponding Frictional force value defined as μR where R is the corresponding compressive force which acts simultaneously.

G. Frictional Contact
The frictional contact was made between the two bars by using the contacts and made the two surfaces adjust to touch then the friction was applied between the surfaces. The coefficient of friction varied from 0.1-0.3.



Solution cell is used to access the Solution branch of the project application.

H. Total Deformation
The location of deformation on the surface or body is given using total option in deformation toolbar and the total deformation on the surface is determined.

III. RESULTS AND DISCUSSION
A bar of length 10cms, breadth 1cm, height 1cm is created using the geometry cell and a surface of dimensions more than the bar has been created. The surface bar below the 10cms bar has been fixed using the fixed support option in supports. A Compressive force was applied on the 10cms bar which varies from 300-800N. A Tensile force was applied on the 10cms bar which varies from 0N to its corresponding Frictional force value defined as μR where R is the corresponding compressive force which acts simultaneously. The frictional contact was made between the two bars by using the contacts and made the two surfaces adjust to touch then the friction was applied between the surfaces. The coefficient of friction varied from 0.1-0.3. The location of deformation on the surface or body is given using total option in deformation toolbar and the total deformation on the surface is determined.

Table 1 For compressive force of 300N and coefficient of friction μ=0.3

Tensile force in N	Deformation in m	
	Min	Max
0	2.2899e-8	5.2138e-8
30	2.204e-8	7.5457e-8
60	2.1363e-8	1.559e-7
90	3.2811e-8	3.1184e-7
>90	The bar displaces	

Table 2 For compressive force of 400N and coefficient of friction μ=0.3

Tensile force in N	Deformation in m	
	Min	Max
0N	3.0512e-8	6.9518e-8
30N	2.9683e-8	8.4713e-8
60N	2.8842e-8	1.4483e-7
90N	2.8500e-8	2.4711e-7
120N	4.3747e-8	4.1579e-7
>120	The bar displaces	

Table 3 For compressive force of 500N and coefficient of friction μ=0.3

Tensile force in N	Deformation in m	
	Min	Max
0	3.8165e-8	8.6897e-8
30	3.7322e-8	9.611e-8
60	3.6448e-8	1.4513e-7
90	3.5757e-8	2.2546e-7
120	3.5864e-8	3.4157e-7
150	5.4684e-8	5.1947e-7
>150	The bar displaces	

Table 4 For compressive force of 600N and coefficient of friction μ=0.3

Tensile force in N	Deformation in m	
	Min	Max
0	4.5798e-8	1.0428e-7
30	4.4959e-8	1.0833e-7
60	4.4080e-8	1.5091e-7
90	4.3264e-8	2.1752e-7
120	4.2725e-8	3.1181e-7
150	4.1343e-8	4.378e-7
180	6.5621e-8	6.2368e-7
>180	The bar displaces	

Table 5 For compressive force of 700N and coefficient of friction μ=0.3

Tensile force in N	Deformation in m	
	Min	Max
0	5.3435e-8	1.2166e-7
30	5.2594e-8	1.2151e-7
60	5.1726e-7	1.5928e-7
90	5.0857e-8	2.1646e-7
120	5.0180e-7	2.9647e-7
150	4.9807e-8	4.0183e-7
180	5.1168e-8	5.3545e-7
210	7.6558e-8	7.2764e-7
>210	The bar displaces	

Table 6 For compressive force of 800N and coefficient of friction μ=0.3

Tensile force in N	Deformation in m	
	Min	Max
0	6.1093e-8	1.3904e-7
30	6.023e-8	1.3886e-7
60	5.9366e-8	1.6943e-7
90	5.8489e-8	2.1983e-7
120	5.7685e-8	2.8967e-7
150	5.7089e-8	3.8067e-7
180	5.7000e-8	4.9423e-7
210	5.9027e-8	6.3354e-7
240	8.7495e-8	8.3159e-7
>240	The bar displaces	

Table 7 For compressive force of 300N and coefficient of friction μ=0.2

Tensile force in N	Deformation in m	
	Min	Max
0	2.3521E-8	5.2098E-8
20	2.249E-8	6.2659E-8
40	2.1078E-8	1.1823E-7
60	2.3089E-8	2.2424E-7
>60	The bar displaces	

Table 8 For compressive force of 400N and coefficient of friction μ=0.2

Tensile force in N	Deformation in m	
	Min	Max
0	3.31E-8	6.9464E-8
20	3.3073E-8	7.3101E-8
40	2.9119E-8	1.1361E-7
60	2.7656E-8	1.8494E-7
80	3.0785E-8	2.9898E-7
>80	The bar displaces	

Table 9 For compressive force of 500N and coefficient of friction μ=0.2

Tensile force in N	Deformation in m	
	Min	Max
0	3.9201E-8	8.683E-8
20	3.8218E-8	8.6995E-8
40	3.7064E-8	1.1755E-7
60	3.5660E-8	1.7278E-7
80	3.4384E-8	2.5436E-7
100	3.8482E-8	3.7373E-7
>100	The bar displaces	

Table 10 For compressive force of 600N and coefficient of friction μ=0.2

Tensile force in N	Deformation in m	
	Min	Max
0	4.7041E-8	1.0420E-7
20	4.6080E-8	1.0390E-7
40	4.4980E-8	1.2530E-7
60	4.3678E-8	1.7042E-7
80	4.2156E-8	2.3646E-7
100	4.1317E-8	3.2524E-7
120	4.6178E-8	4.4848E-7
>120	The bar displaces	

Table 11 For compressive force of 700N and coefficient of friction μ=0.2

Tensile force in N	Deformation in m	
	Min	Max
0	5.4881E-8	1.2156E-7
20	5.3903E-8	1.2134E-7
40	5.2308E-7	1.3250E-7
60	5.1726E-8	1.5928E-7
80	5.1141E-7	1.9490E-7
100	5.0595E-8	2.4046E-7
120	5.0180E-8	2.9677E-7
140	4.9846E-8	3.6378E-7
>140	The bar displaces	

Table 12 For compressive force of 800N and coefficient of friction μ=0.2

Tensile force in N	Deformation in m	
	Min	Max
0	6.2722E-8	1.3893E-7
20	6.1754E-8	1.3870E-7
40	6.0745E-8	1.4620E-7
60	5.9556E-8	1.7976E-7
80	5.8238E-8	2.7220E-7
100	5.6755E-8	2.9028E-7
120	5.5313E-8	3.6987E-7
140	5.5274E-8	4.6922E-7
160	6.1571E-8	5.9797E-7
>160	The bar displaces	

Table 13 For compressive force of 300N and coefficient of friction μ=0.1

Tensile force in N	Deformation in m	
	Min	Max
0	2.5142E-8	5.1955E-8
10	2.4034E-8	5.5994E-8
20	2.1537E-8	8.2032E-8
30	2.1210E-8	1.4473E-7
>30	The bar displaces	

Table 14 For compressive force of 300N and coefficient of friction μ=0.1

Tensile force in N	Deformation in m	
	Min	Max
0	3.3523E-8	6.9274E-8
10	3.2536E-8	7.2241E-8
20	3.0657E-8	8.5066E-8
30	2.7514E-8	1.253E-7
40	2.8280E-8	1.9297E-7
>40	The bar displaces	

Table 15 For compressive force of 300N and coefficient of friction μ=0.1

Tensile force in N	Deformation in m	
	Min	Max
0	4.1903E-8	8.6592E-8
10	4.1012E-8	8.8797E-8
20	3.9421E-8	9.6779E-8
30	3.36978E-8	1.2316E-7
40	3.3646E-8	1.6947E-7
50	3.5349E-7	2.4121E-7
>50	The bar displaces	

Table 16 For compressive force of 300N and coefficient of friction μ=0.1

Tensile force in N	Deformation in m	
	Min	Max
0	5.0284E-8	1.0391E-7
10	4.9473E-8	1.0544E-7
20	4.8068E-8	1.1199E-7
30	4.5976E-8	1.2700E-7
40	4.3073E-8	1.6408E-7
50	3.9862E-8	2.1486E-7
60	4.2419E-8	2.8945E-7
>60	The bar displaces	

Table 17 For compressive force of 300N and coefficient of friction μ=0.1

Tensile force in N	Deformation in m	
	Min	Max
0	5.8664E-8	1.2123E-7
10	5.7917E-8	1.2224E-7
20	5.6602E-8	1.2816E-7
30	5.4857E-8	1.3789E7
40	5.2361E-8	1.6510E-7
50	4.9168E-8	2.0726E-7
60	4.6181E-8	2.6176E-7
70	4.9489E-8	3.3769E7
>70	The bar displaces	

Table 18 For compressive force of 300N and coefficient of friction μ=0.1

Tensile force in N	Deformation in m	
	Min	Max
0	6.7045E-8	1.3855E-7
10	6.6535E-8	1.3910E-7
20	6.5071E-8	1.4990E-7
30	6.3484E-8	1.5249E7
40	6.1301E-8	1.7031E-7
50	5.8472E-8	2.0519E-7
60	5.5028E-8	2.5059E-7
70	`5.2618E-8	3.0790E-7
80	5.6559E-8	3.8593E-7
>80	The bar displaces	

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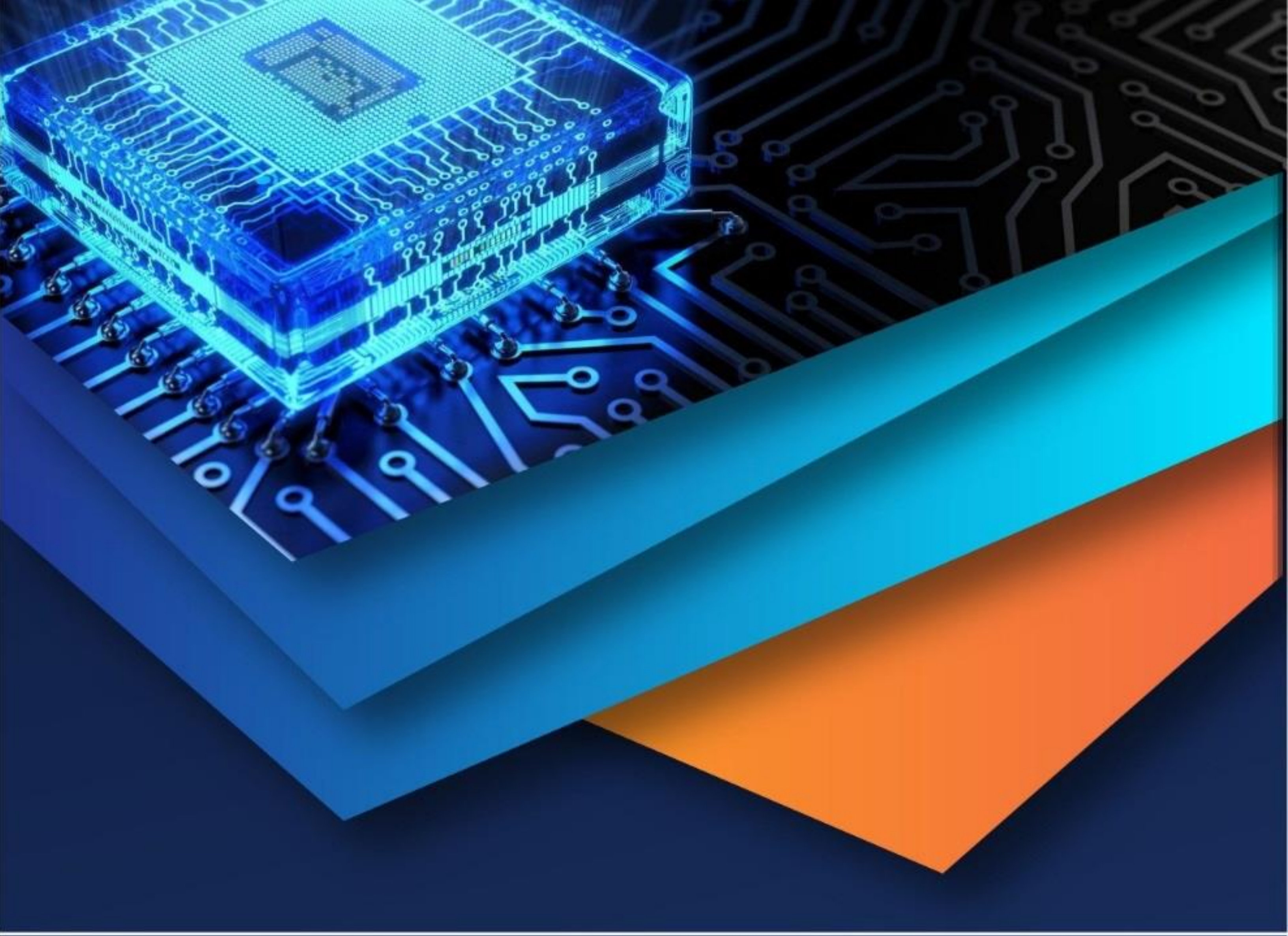

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