where E is Young's Modulus and μ is the Poisson's ratio.

2- Secondary (or Transverse or Shear) waves (S-Waves) : In ***transverse waves,*** the particle motion is normal to the direction of propagation. Their velocity, V_S , is

$$\rho V^2_S = E \,/\, [\, 2\,(\,1+\mu\,)\,] \qquad (4.8)$$

(see above for explanation of symbols).
From the equations: (a) both velocities are independent of amplitude or period of the waves; and (b) V_P is always greater than V_S, hence the longitudinal waves are the first to arrive at any detector.

Seismic waves obey the same relation among frequency f , wavelength λ, and wave spread $\mathbf{v}$ as do light waves and sound waves in air, that is:

$$f\lambda = \mathbf{v} \qquad (4.9)$$

In SI base units, frequency is expressed in hertz (Hz), wavelength in m, and velocity in m/s. Of the obvious parameters appearing in above Eq. (11.9), it is the wave velocity that will be of primary concern. By measuring the distance L between the rock faces, the velocities V_P and V_S of the P and S waves can be calculated by:

$$V_P = L \,/\, t_P \quad ; \quad V_S = L \,/\, t_S \qquad (4.10)$$

Where t_P is the time required for the P wave to reach the opposite face, and t_S is the corresponding quantity for the S wave. In fact , for any tock tested, it is found that $t_P < t_S$, which means that $V_P > V_S$. P waves travel faster than S waves. In addition, P and S wave velocities depend upon elastic properties of the rock that transmits the waves and its density. Thus, formula of P and S wave velocities can be derived in terms of the moduli that describe the elastic properties of the rocks. The formulas are:

$$V_P = [E\,(\,1-\mu\,)\,/\,\{\,\rho\,(\,1+\mu\,)\,(\,1-2\,\mu\,)\}\,]^{1/2} \qquad (4.11)$$

$$V_S = (\,G\,/\,\rho\,)^{1/2} = [\,E \,/\, \{2\,\rho\,(\,1+\mu\,)\}\,]^{1/2} \qquad (4.12)$$

Where E is the Young's modulus; G shear modulus; μ Poisson' s ratio; and ρ the density of the rock.

4.2.3.3 Moduli from Wave Velocities

As elastic moduli describe the deformation in rocks under a specific mode of loading either ***static loading*** or ***dynamic loading***. As civil engineer is interested in obtaining such constants, so the knowledge of the wave velocities allows calculation of the elastic moduli without subjecting the rock to actual loading and deformation in the laboratory. So the required moduli as given from their defining equations with respect to wave velocities are:

1- Young's modulus (*E*): Its unit is Pa

$$V_P = [E\,(1-\mu)\,/\,\{\rho\,(1+\mu)\,(1-2\mu)\}]^{1/2} \quad ;$$

$$E = [\rho\, V^2_P (1+\mu)\,(1-2\mu)]\,/\,(1-\mu) \qquad (4.13)$$

2- Poisson's ratio (*μ*): It is unitless**.**

$$\mu = (V^2_P - 2\,V^2_S)\,/\,(2\,V^2_P - V^2_S) \qquad (4.14)$$

3- Shear modulus (*G*): Its unit is Pa

$$V_S = (G\,/\,\rho)^{1/2} \quad ;$$

$$G = \rho\, V^2_S \qquad (4.15)$$

4- Bulk modulus (or Incompressibility)(*k*): Its unit is Pa.

$$V_P = [(k + 4/3\,G)\,/\,\rho\,]^{1/2}$$

$$K = \rho\, V^2_P - (4/3\,G) \qquad (4.16)$$

Its reciprocal is ***K*** the incompressibility**.**

EXAMPLE 4.4: Find the density and bulk modulus of a rock has wave velocities 3.95 km/s and 5.82 km/s and shear modulus 37.6 GPa.

As $V_P > V_S$; so V_P = 5.82 km / s and V_S = 3.95 km/s
$V_S = (G/\rho)^{1/2}$
3950 km / s = (37.6 * 10^9 Pa / ρ)$^{1/2}$
ρ = 2410 kg / m^3
$V_P = [(k + 4/3\,G)/\rho\,]^{1/2}$
5820 m / s = [{k + 4/3 (37.6 * 10^9 Pa)} / 2410 km / m^3]$^{1/2}$
k = 3.149 *10^{10} Pa
k = 31.5 GPa

EXAMPLE 4.5: Calculate the velocities of P and S waves in a rock has bulk modulus of 11.916 GPa, a shear modulus of 7.932 GPa, and a density equal to 2.62 gm/cm^3.

ρ = 2.62 gm / cm^3 = 2620 kg / m^3

$V_P = [(k + 4/3\ G) / \rho]^{1/2}$

$V_P = [\{11.916*10^9\ Pa + 4/3\ (7.932 * 10^9\ Pa)\} / 2620\ kg / m^3]^{1/2}$

$V_P = 2930\ m / s = 2.93\ km / s$

$V_S = (G / \rho)^{1/2}$

$V_S = (7.932 * 10^9\ Pa / 2620\ kg / m^3)^{1/2}$

$V_S = 1740\ m / s = 1.74\ km / s$

EXAMPLE 4.6: A rock has S wave velocity of 3.4 km/s, a density of 2.7 gm/cm^3 and Poisson**'s** ratio of 0.36. Calculate:
a- the velocity of P wave velocity in the rock.
b- all elastic constants that could be determined.

$V_S = [E / \{2 \rho (1+ \mu)\}]^{1/2}$

$V^2_S = E / [2 \rho (1+ \mu)]$

$(3400\ m / s)^2 = E / [2\ (2700 kg / m^3)\ (1+ 0.36)]$

$E = 8.489*10^9\ Pa$

$E = 84.9\ GPa$

$V_P = [E(1 - \mu) / \{\rho (1+ \mu)(1 - 2 \mu)\}]^{1/2}$

$V^2_P = E(1 - \mu) / [\rho (1+ \mu)(1 - 2 \mu)]$

$V^2_P = 84.9 *10^9\ Pa\ (1 - 0.36) / [2700 kg / m^3\ (1+ 0.36)(1 - 2 * 0.36)]$

$V_P = 7269.64\ m / s = 7.27\ km / s$

$V_S = (G / \rho)^{1/2}$

$G = \rho V^2_S$

$G = (2700\ kg / m^3)(3400\ m / s)^2$

$G = 3.12 * 10^{10}\ Pa = 31.2\ GPa$

$V_P = [(k + 4/3\ G) / \rho]^{1/2}$

$V^2_P = (k + 4/3\ G) / \rho$

$(7270\ m / s)^2 * (2700\ kg / m^3) = k + [4/3\ (3.12* 10^9\ Pa)]$

$k = 1.011 * 10^{11}\ Pa = 101\ GPa$

4.2.3.4 Seismic Techniques

Seismic methods can be divided according to their applied type of waves into two methods:

1- **Seismic Reflection Method**: It depends upon reflected waves and it is used almost exclusively in the petroleum exploration and for structural and lithological boundaries in great depths.

2- Seismic Refraction Method: It depends upon refracted waves and it is used mainly for finding the thickness of unconsolidated deposits at shallow depths.

In the applied seismic methods, waves are generated at a ***shot point*** usually by firing off a small explosive charge electrically or, in adaptations of the method, by ***dropping a weight*** or by hitting a metal plate with a ***sledgehammer***. The arrival of the waves at various stations on a line of traverse is detected by ***seismometers*** (***geophones***) planted at the surface, or by ***hydrophones*** in water-covered areas. These convert ground or water motions into a varying electrical current. This is transmitted along wires linking each detector to a ***seismograph*, where the output from each channel is amplified and recorded. On the seismic record **(*seismogram*),** the ground motion at each detector is represented by a line of wiggles on one trace of the record. The time taken by the waves as they follow different paths between shot point and detector can be measured as the moment of explosion, and time marks (usually at 0.01 s) are recorded also.

In the simplest and most commonly used seismic-refraction method (Fig. 4.3), only the times of the first pulse of energy to arrive at each detector are used. For this reason, seismic-refraction apparatus is simpler and cheaper than that needed for seismic reflection surveys, in which more complex electronic equipment is essential to give a useful record of later, reflected arrivals. The ***first arrivals*** at detectors close to the shot point travel directly along the ground surface. A plot of arrival times ***(T)*** against distance ***(X)*** of each corresponding detector from the shot point gives a straight line. Its gradient is the reciprocal of the velocity (V_1) of the rock at the surface.

Slope = Time / Distance = 1/ (Distance / Time) = 1 / velocity = 1 / V (4.17)

Thus, if the waves penetrate two layers, then two straight lines with different slopes (i.e. 1 / V_1 and 1 / V_2) are formed and intersected at a point which is called the cross-over point.

In refraction method waves, the waves pass through the upper layer across the interface and penetrate into the lower layer. In the lower layer, they travel at the velocity of waves in that layer, which is V_2 . Hence, their travel times depend on V_2 as well as V_1 . Figure (4.3) shows the refracted waves produced by waves reaching the interface from the shot point (S). If the rock layer below layer V_1 has a higher velocity V_2 (i.e. $V_2 > V_1$), there is a critically refracted ray which travels along the top of V_2 . If layers V_1 and V_2 are coupled mechanically, such that the top of V_2 cannot vibrate without exciting waves at the base of V_1 (and this is the natural state of subsurface rocks), then waves pass through the interface from layer V_2 to V_1 , and in the process are refracted to continue towards the surface at an angle i_c to the normal. Paths of this type (where the ray first plunges through layer V_1 at the critical angle, then the wave travels rapidly along the top of refractor V_2 , emerging through layer V_1 at the critical angle) gradually overtake the direct ray. The delay in going down to and up from V_2 is compensated as ***X*** increases by faster travel through the refractor. Critically refracted compressional ***P***-waves eventually become the first to arrive at the detectors beyond a particular value of ***X***. The gradient of the ***T-X*** values of these arrivals bears a simple relation to the velocity of a horizontal refractor. If the straight line of the first layer is

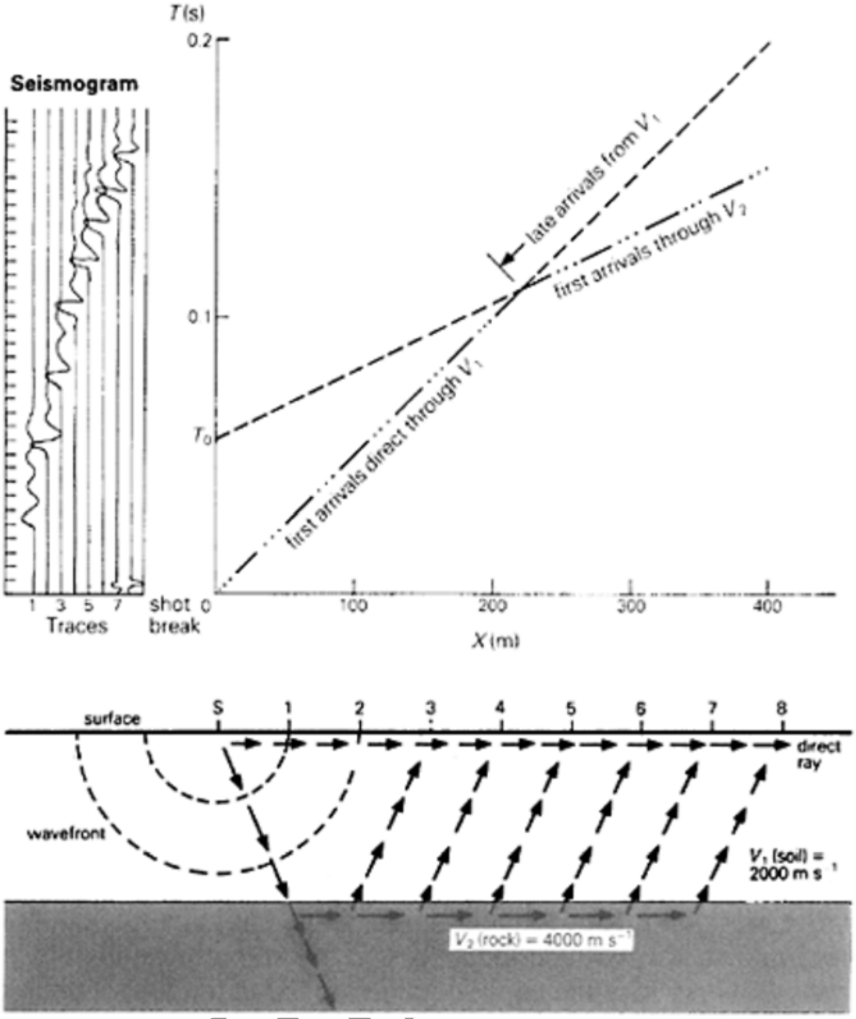


Fig.(4.3). An explosive charge, fired at the shot point S, generates body and surface waves which propagate in all directions from S. Only the rays and wavefronts of the longitudinal *(P)* waves are represented, since with their higher velocity relative to the other types of wave they arrive first at the detectors laid out along the spread (traverse) being surveyed. The corresponding time-distance *(T-X)* graph is a plot of these first-arrival times against distance *X* from S. The graph consists of two straight-line segments, each of which is related to one of the two velocity layers V_1 (soil) and V_2 (bedrock) distance *X* from S. The graph consists of two straight-line segments, each of which is related to one of the two velocity layers *V* 1 (soil) and *V* 2 (bedrock). The interpretation of the *T-X* graph is discussed in the text.

extended to $T = 0$, thus time is referred to as ***time intercept*** (T_i), or T_0 in the Figure. While the intersection points of the straight lines is called the ***cross-over point***, where its distance from the shot point is called the ***critical distance*** (X_c). Thus the depth z_1 from surface to interface may be obtained from the ***T-X*** graph, using the critical distance by equation:

$$z_1 = X_{c1} / 2 \ [(V_2 - V_1) / (V_2 + V_1)]^{1/2} \qquad (4.18)$$

or by means the intercept time by equation:

$$z_1 = V_1 V_2 T_{i1} / [\ 2\,(V^2{}_2 - V^2{}_1)\ ]^{1/2} \tag{4.19}$$

T_{i1} is the intercept on the time axis (***X*=0**) of the projection of the velocity segment on the graph which corresponds to V_2 arrivals. The velocities V_1 and V_2 are obtained from the gradients of the corresponding velocity segments. This theory can be extended to derive the depth of each of ***n*** horizontal interfaces separating velocity layers where the velocity increases with depth and every layer is recorded on the ***T-X*** graph as a straight-line segment. But we will consider only the simple case, two-layers case. In case of dipping interface model , it is needed to define the distribution of velocities more precisely, so it is preferable to make "***shooting both ways***" or ***reverse shooting***.

Applications of Seismic Refraction Technique in Civil Engineering

1- It is important for site investigation to detect the subsurface rocks (such as bedrock) and their different properties, such as for dam site investigations.
2-Determining the subsurface layers velocities and depths (or thicknesses) and their extensions and locating the regions of weakness.
3- Delineating fracture zones, such as joints, faults and cavities.
4- It is important for ground studies such as detecting groundwater levels and water quality.
5- Mapping buried channels, gravel and sand deposits.
6-It is important in soil investigations for estimating some geotechnical properties from seismic velocities and to correlate the measures between them such as for Standard Penetration Test (SPT).

EXAMPLE 4.7: A seismic refraction surveying team takes in a site , the time-distance curve shows that the first critical distance X_{c1} is of 1200 m from the source ant the critical time T_{c1} of 0.4 s, while the second critical distance X_{c2} is of 3200 m from the source ant the critical time T_{c2} of 0.6 s. It is required to find: 1- velocity of the first layer ; 2- velocity of the second layer ; and 3- the depth to the horizontal interface.

1- As X_{c1}=1200 m and T_{c1} = 0.4 s ; so $V_1 = X_{c1} / T_{c1}$=1200 m / 0.4 s=3000 m/ s
2- As the cross-over point represents the beginning of the first critical distance X_{c1} at a distance 1200 m and time 0.4 m, and waves from the second layer at a distance of 3200 m and time 0.6 s and then the velocity of the second layer is:

$V_1 = (X_{c2} - X_{c1}) / (T_{c2} - T_{c1})$=(3200 m – 1200 m) / (0.6 s – 0.4 s)=10000 ms^{-1}

3- To find the depth (= thickness for the first layer) :

$$z_1 = X_{c1} / 2 \; [(V_2 - V_1) / (V_2 + V_1)]^{1/2}$$

$$z_1 = 1200 \text{ m} / 2 \; [(10000 - 3000) \text{ ms}^{-1} / (10000 + 3000) \text{ ms}^{-1}]^{1/2}$$

$$z_1 = 440 \text{ m}$$

EXAMPLE 4.8: A seismic refraction surveying was carried out in a site, the results of time-distance curve found two layers with velocities 2000 and 4000 m/s for the first and second layers respectively. Find the depth to the horizontal interface, knowing that the critical distance at 0.13 km from the source.

$$z_1 = X_c / 2 \; [(V_2 - V_1) / (V_2 + V_1)]^{1/2}$$

$$z_1 = 130 \text{ m} / 2 \; [(6000 - 2000) \text{ ms}^{-1} / (6000 + 2000) \text{ ms}^{-1}]^{1/2}$$

$$z_1 = 45.96 \text{ m}$$

EXAMPLE 4.9: A seismic refraction survey was made for a hydroelectric project. The results of time-distance curve found two layers with velocities 600 and 1200 m/s for the first and second layers respectively, the critical distance was 180 m from the source and the time intercept of the second layer T_{i1} was 150 s. Find the depth to the boundary separating the two layers using:

1- the critical distance ; 2- the time intercept

$$z_1 = X_c / 2 \; [(V_2 - V_1) / (V_2 + V_1)]^{1/2}$$

$$z_1 = 180 \text{ m} / 2[(1200 - 600) \text{ ms}^{-1} / (1200 + 600) \text{ ms}^{-1}]^{1/2}$$

$$z_1 = 51.96 \text{ m}$$

$$z_1 = V_1 V_2 T_{i1} / [2 (V^2_2 - V^2_1)]^{1/2}$$

$$z_1 = (1200 \text{ ms}^{-1})(600 \text{ ms}^{-1})(0.15 \text{ s}) / [2 \{(1200 \text{ ms}^{-1})^2 - (600 \text{ ms}^{-1})^2 \}]^{1/2}$$

$$z_1 = 51.96 \text{ m}$$

4.2.4 Ground Probing (Penetrating) Radar (GPR)

4.2.4.1 Basic Theory

GPR stands for Ground Probing Radar, is also called ***Ground Penetrating Radar*** and as the name suggests, it is a technique for probing the ground. GPR is a geophysical method that uses radar pulses to image the subsurface. This non-destructive method uses electromagnetic radiation in the microwave band (UHF/VHF frequencies) of the radio spectrum, and detects the reflected signals from subsurface structures. GPR can be used in a variety of media, including rock, soil, ice, fresh water, pavements and structures. It can detect objects, changes in material, and voids and cracks. Like any other radar, it works by sending an electromagnetic wave into the ground and recording the returning signals that reflected from the subsurface horizons. These returning signals contain information about the materials, or to be exact about the changes in materials or penetrates of the ground at different depths.

GPR uses transmitting and receiving antennas or only one containing both functions (Fig. 4.4). The transmitting antenna radiates short pulses of the high-frequency (usually polarized) radio waves into the ground. When the wave hits a buried object or a boundary with different dielectric constants, the receiving antenna records variations in the reflected return signal. The principles involved are similar to reflection seismology, except that electromagnetic energy is used instead of acoustic energy, and reflections appear at boundaries with different dielectric constants instead of acoustic impedances.

It is known that most of soils and rocks have very low conductivity (about < 10^{-2} S/m) thus the electromagnetic waves propagation is mainly affected by electrical dielectric constants of soils and rocks. The applied frequencies used are considered low compared with that of Radar frequencies to ascertain their penetration inside earth layers.

The propagation of the radar signals into earth layers depends upon the electromagnetic properties of soils and rocks which are:

1- Dielectric Permittivity (ε)

2- Electrical conductivity (σ)

Thus if these properties are changed abruptly at the layer interfaces so part of the energy will be reflected as in seismic reflection as shown in Fig. (4.4).

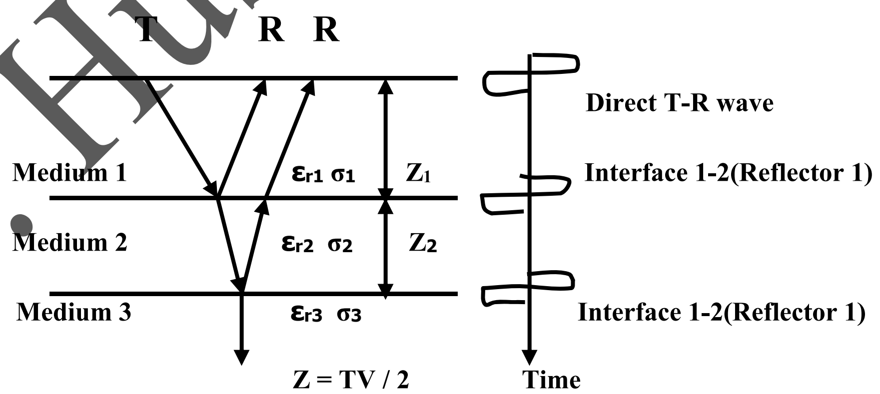


Fig. (4.4). GPR transmitting and receiving signals.

The propagation of electromagnetic (***EM***) waves at frequencies in the range of megahertz (radar pulse) is mainly controlled by the dielectric properties of the rock material. The velocities of propagation of radar signal are related to the relative dielectric constant relative permittivity (or relative dielectric constant) (ε_r):

$$V = c/(\mu_r \varepsilon_r)^{1/2} \quad (4.20)$$

where ε_r (= $\varepsilon/\varepsilon_0$) is the ratio of the dielectric permittivity of the medium to the dielectric permittivity of free space **(=8.85*10^{-12}F/m)**, μ_r (=μ/μ_0) is the relative permeability of the medium which is about unity for most earth soils and rocks, and ***c* = 3*10^8 m/s (=0.3 m/ns)** is the velocity of EM waves in free space. Since μ_r is close to unity for most rock materials (except a few strongly magnetic rocks), radar velocity is primarily controlled by the dielectric constant of the medium as $\mu_r \approx 1$:

$$V = c/(\varepsilon_r)^{1/2} \quad (4.21)$$

In comparison with water for which ε_r =81, most geological formations have much lower values, the lowest values (in the range 3–10) being dry sand / gravel and silt, unaltered hard rocks, permafrost soils and ice.

GPR uses transmitting and receiving antennas or only one containing both functions. The transmitting antenna radiates short pulses of the high-frequency (usually polarized) radio waves into the ground. When the wave hits a buried object or a boundary with different dielectric constants, the receiving antenna records variations in the reflected return signal. The principles involved are similar to reflection seismology, except that electromagnetic energy is used instead of acoustic energy, and reflections appear at boundaries with different dielectric constants instead of acoustic impedances.

It is appropriate to use GPR if there are sharp differences in properties of the materials being surveyed. If the differences of the materials are small or their changes gradual then the returning signal are difficult to interpret in many case just impossible. GPR is well suited for geophysical, archeological surveys and civil engineering applications to locate hidden objects in the ground.

If the properties of the materials are trying to survey are not distinct enough then it becomes hard to detect them. We can use the concept of reflection coefficient to understand better the idea behind the materials contrast. The ***reflection coefficient*** (***ρ***) is the ratio of the difference of the square roots of the relative dielectric constant of the two interface materials to the sum of the square roots of the relative dielectric constant of the two materials:

$$R = (\varepsilon_{r2}^{1/2} - \varepsilon_{r1}^{1/2}) / (\varepsilon_{r1}^{1/2} + \varepsilon_{r2}^{1/2}) \quad (4.22)$$

where ε_{r1} is the relative dielectric constant of the overlying material; and ε_{r2} is the relative dielectric constant of the underlying material.

The reflection coefficient (***R***) can take positive or negative values, but for the purpose of the tutorial we are going to be concerned with the absolute value if it not the sign. Then, if it is correct to say that the reflection coefficient takes values

ranging from 0.0–1.0 .The closer the reflection coefficient gets to one the better for ground penetrating radar survey. Thus, the reflection coefficients grades are:
1- Weak reflection coefficient ($-0.2 < \boldsymbol{R} < 0.2$).
2- Intermediate reflection coefficient ($0.2 < \mathbf{R} < 0.35$) or ($-0.35 < \boldsymbol{R} < -0.2$).
3- High reflection coefficient ($0.35 < \boldsymbol{R} < 1.0$) or ($-1.0 < \boldsymbol{R} < -0.35$).

The energy reflected is directly proportional to the reflection coefficient. As the thickness of a layer or object decreases the energy reflected also decreases depending on the thickness and signal wavelength in the medium. Thus, the resolution power of GPR is controlled by the layer thickness. The resolution increases when the distance between any two interfaces becomes, at least, equal to quarter of the radar signal.

Water plays an important role in the attenuation of the EM waves and it affects the GPR survey. The higher the conductivity of the materials we are trying to survey the higher the attenuation of the electromagnetic waves penetrating the media and therefore the less we can "see" into the ground. Highly electrical conductive media are salt water, and some types of clay particularly if they are wet. Agricultural soils containing soluble fertilizer like nitrogen or potassium can be highly conductive as well.

How does water affect the GPR survey?
1- Soils-containing water have high electrical conductivity.
2- Water particles absorb energy with high frequency (> 1000 MHz). Thus high frequencies are used for shallow depth investigations, while low frequencies are used for large depth investigations.

The depth range of GPR is limited by the electrical conductivity of the ground, the transmitted center frequency and the radiated power. As conductivity increases, the penetration depth also decreases. This is because the electromagnetic energy is more quickly dissipated into heat, causing a loss in signal strength at depth. Higher frequencies do not penetrate as far as lower frequencies, but give better resolution. Optimal depth penetration is achieved in ice where the depth of penetration can achieve several hundred meters. Good penetration is also achieved in dry sandy soils or massive dry materials such as granite, limestone, and concrete where the depth of penetration could be up to 15 m. In moist and/or clay laden soils, saturated concrete and soils with high electrical conductivity, penetration is sometimes only a few centimeters. The depth of penetration is related with the electrical conductivity by the following general formula:

$$\boldsymbol{D = 35 / \sigma} \tag{4.23}$$

where $\boldsymbol{D}$ is the depth of penetration in (m) and $\boldsymbol{\sigma}$ is the electrical conductivity in (mS/m).

4.2.4.2 Applications of GPR in Civil Engineering and Limitations

GPR has many applications in a number of fields:
1- In the ***Earth sciences***: It is used to study bedrock, soils, groundwater, and ice.
2- In ***Engineering applications*** include nondestructive testing (***NDT***) of structures and pavements, locating buried structures and utility lines, and studying soils and bedrock.

a- The advantages of using GPR are many; first of all it is a relatively inexpensive way of surveying large areas without destroying or corrupting anything. Non-destructive-Ground Penetrating Radar provides a non-Destructive means to locate items within materials.

b- GPR provides an easy way of estimating depth to layers, ground waters, bedrock, caves and many other underground or under surface phenomena without the need for digging.

c- GPR systems have no problem what so ever to find metallic or non-metallic pipes, electrical cables hidden underground, concrete conduits etc.(Picture on the left showing a hyperbola in the B-Scan, which is typical for pipes) .

d- GPR can be used to visualize numerous materials, voids, cracks, and leaks at slab grade.

e- GPR reduces the time needed to meet your deadlines. GPR can locate items in real time avoiding film developing times. GPR operates in real time. Scans are available within minutes.

3- In ***environmental remediation***: It is used to define landfills, contaminant plumes, and other remediation sites.
4- In ***archaeology***: It is used for mapping archaeological features and cemeteries. It is used in law enforcement for locating clandestine graves and buried evidence.
5- In ***military***: Its uses include detection of mines, unexploded ordnance, and tunnels.

Limitations

The most significant performance limitation of GPR is poor performance in high-conductivity materials such as clayey soils. Performance is also limited by signal scattering in heterogeneous conditions (e.g. rocky soils).
Other disadvantages of currently available GPR systems include:

- Interpretation of radargrams is generally non-intuitive.
- Considerable expertise is necessary to effectively design, conduct, and interpret GPR surveys.
- The cost of GPR equipment and software is relatively high.
- Relatively high energy consumption can necessitate large cumbersome batteries for extensive surveys.

4.2.4.3 Examples of Jobs Performed

A leaking pipe at slab grade was identified to limit the digging necessary to replace the segment of pipe below a residential property. The location of a leak in a subsurface pipe is undetectable by any other means. An underground tank was located using GPR for replacement. The tank was to be reused for another purpose and could not be damaged. GPR was used to locate the tank. The size, shape, and depth were located quickly and the tank successfully removed. If concrete coring is being done the technician will identify a safe area without cutting rebar or Post Tension Cables. Ground Penetrating Radar can aid Law Enforcement by locating evidence or burial grounds (Figs. 4.5 and 4.6).

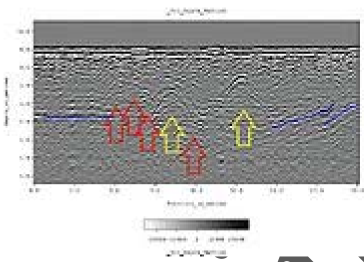


Fig. (4.5). A ground - penetrating radargram collected on an historic cemetery in Alabama, USA. Hyperbolic reflections indicate the presence of reflectors buried beneath the surface, possibly associated with human burials.

Fig. (4.6). Other examples for ground-penetrating radargram.

EXAMPLE 4.10: If the time for receiving radar signal from a subsurface reflector is 2.4 s where the reflector depth is 408 m from earth surface. Find the radar wave velocity in the reflector?

$Z = (L^2 - X^2)^{1/2}$

For large depths $Z \approx L$; so

$Z = L = V(T/2)$

$V = Z/(T/2) = 408 \text{ m} / (2.4 \text{ s} / 2) = 340 \text{ m/s}$

EXAMPLE 4.11: A subsurface refractor interface has been detected by ultrasonic waves at a specific depth from earth surface, if the wave frequency is 500 kHz and its wavelength 0.003 m and the knowing that the transmitting signal has been received after 4.0 s. Find the depth to the subsurface reflector?

$V = f \lambda$

V = (500 kHz) (0.003 m) = 1500 m / s

Z = V (T / 2)

Z = (1500 m / s) * (4.0 s / 2) = 3000 m

EXAMPLE 4.12: A radar signal has been introduced into water with a frequency of 1.0 MHz where the average electrical conductivity of water is 4.0 mS/m and the relative dielectric constant of water is 80.0. Find:

1- the radar signal velocity in the water ; 2- the depth of penetration.

$V = c / (\varepsilon_r)^{1/2}$

$V = (3 * 10^8 \text{ m/s}) / (80)^{1/2}$

$V = 3.3510^7 \text{ m/s} = 0.033 \text{ m / ns}$

$D = 35 / \sigma$

D = 35 / (4.0 mS /m)

D = 8.75 m

EXAMPLE 4.13: A radar signal sent out by a GPR into two different media dry sand and wet clay. It is found their relative dielectric constants were 10.0 and 40.0 respectively and the electrical conductivity of the dry sand was 0.01 S/m. Find:

1- the reflection coefficient and its grade ; 2- the radar wave velocities in the two media ; 3- the depth of penetration.

1-

$R = (\varepsilon_{r2}^{1/2} - \varepsilon_{r1}^{1/2}) / (\varepsilon_{r1}^{1/2} + \varepsilon_{r2}^{1/2})$

$R = (40.0^{1/2} - 10.0^{1/2}) / (10.0^{1/2} + 40.0^{1/2})$

R = (6.3 – 3.2) / (2.3 +6.3) = 0.32

By using the grades of the reflection coefficient, with the value of R = 0.32 it is of intermediate reflection coefficient.

2-

$V = c / \varepsilon_r)^{1/2}$

$V_1 = c / (\varepsilon_{r1})^{1/2} = (3 * 10^8 \text{ m / s}) / (10.0)^{1/2} = 9.48 * 10^7 \text{ m / s}$

$V_2 = c / (\varepsilon_{r2})^{1/2} = (3 * 10^8 \text{ m / s}) / (40.0)^{1/2} = 4.74 * 10^7 \text{ m / s}$

3-

$D = 35 / \sigma$

D= 35 / (0.01 S / m) = 35 / 10.0 mS / m = 3.5 m

4.2.5 Electromagnetic Methods

4.2.5.1 Basic Theory

Electromagnetic Methods use an ***EM*** field generated by a transmitter coil through which an alternating current is passed. This generated a magnetic field around the transmitter coil. These methods generally use frequencies in the range between 100 and 5000 Hz, but radio waves of higher frequencies are also used. When the transmitter coil is held near the earth, the magnetic field induces an electrical field in the earth. The electrical field will travel through the ground at different strength depending upon the ground conductivity. The field strength is measured in a passive receiver coil. Changes in the phase, amplitude, and orientation of the primary field can be measured either with time or distance by using the receiver. These changes are related to the electrical such as electrical resistivity (***ρ***), magnetic permeability (***μ***), the frequency of the EM field and the type of the soil and rock cover. There are several different EM methods available.

4.2.5.2 Applications of EM Methods in Civil Engineering

1- They are all have the advantage of being rapid and less expensive.
2- The techniques are very effective in minerals prospecting such as conductive bodies.
3- They can be used to detect changes in the earth conductivity related to contaminant plumes, buried metallic waste such as plumes or salt-water interfaces.
4- They can be used in groundwater investigations such as mapping groundwater levels and subsurface cavities and caves .
5- The technique has been used effectively in mapping buried channels where channel-filling material has a resistivity contrast with the enclosing medium.

4.2.6 Gravity Method

4.2.6.1 Basic Theory

The gravity method depends on the gravitational attraction which is defined by Newton's Law. If the earth is one of the two masses, then its gravitational attraction is more generally described in terms of the acceleration ***g*** it evokes in the other mass. Gravitational acceleration ***g*** has traditionally been expressed in cgs units of cm s^{-2}, called for this purpose a ***gal*** (after Galileo). Its value ranges from just under 978 gal at high altitude at the Equator, to over 983 gal at sea level at the Poles. A smaller unit, the ***milligal*** (equal to 0.001 gal) has conventionally been used in exploration surveys. The gravity method depends on the density contrast across the interface being investigated. Since structures of interest in site exploration are relatively small, the gravity method is usable only if the density contrast is relatively large, and even then only as a reconnaissance method because of poor resolution.

Comparison of observed values of ***g*** corrected for elevation, etc. with the theoretical value for the same station normally shows a difference called the ***Bouguer anomaly*** at the station. Bouguer anomalies exist because the density layering in the earth is not simply concentric . Folds, faults and igneous intrusions bring denser rocks close to the surface in some areas, resulting in anomalous masses with respect to a horizontally layered earth (Fig. 11.7).The magnitude of a Bouguer anomaly is related to the size of structure and to the density contrast across the interface being investigated. Since structures of interest in site exploration are relatively small, the gravity method is usable only if the density contrast is relatively large, and even then only as a reconnaissance method because of poor resolution. This condition is met in two types of problem.

***Gravity meters*,** for example the commonly used Worden Meter, can be read to a precision of 0.01 mgal, though slight irregularities in instrumental drift make the accuracy less. Errors in correcting for elevation, irregular terrain around the meter station, and tidal effects normally reduce the accuracy of a corrected reading to about 0.03 mgal under favorable circumstances (a small flat site), but the error may be closer to 0.1 mgal where topography is irregular. Although this is a small fraction of the total earth's gravity field, it is an insensitive measure of changing subsurface conditions, and for this reason the gravity method has had limited application to engineering problems.

For example, measurements of the pull of gravity at different places (stations) along a traverse can be used to predict how rocks of different density occur below the traverse. If we consider a simple density model, say the left-hand side of Figure 4.7, with only two materials of density 2.0 and 2.5 g cm^{-3} present and separated by a horizontal interface, then the attractive mass distributed under any point at the surface is the same, and the pull of gravity at the surface is constant along the model. Using this as a standard, let us redistribute the materials. If the deeper, denser layer is stepped up towards the surface by a fault (**F** on Fig. 4.7), part of the 2.0 g cm^{-3} layer in the standard model is now substituted by 2.5 g cm^{-3} material. The new density model may be described as differing from the previous, standard model by the addition of a positive ***anomalous mass*** of density +0.5 g cm^{-3}, and of cross-sectional area abcd. This extra mass increases the pull of gravity relative to the "**standard**" value. There is a ***gravity anomaly*** with respect to standard gravity that corresponds to the anomalous mass and indicates its presence.

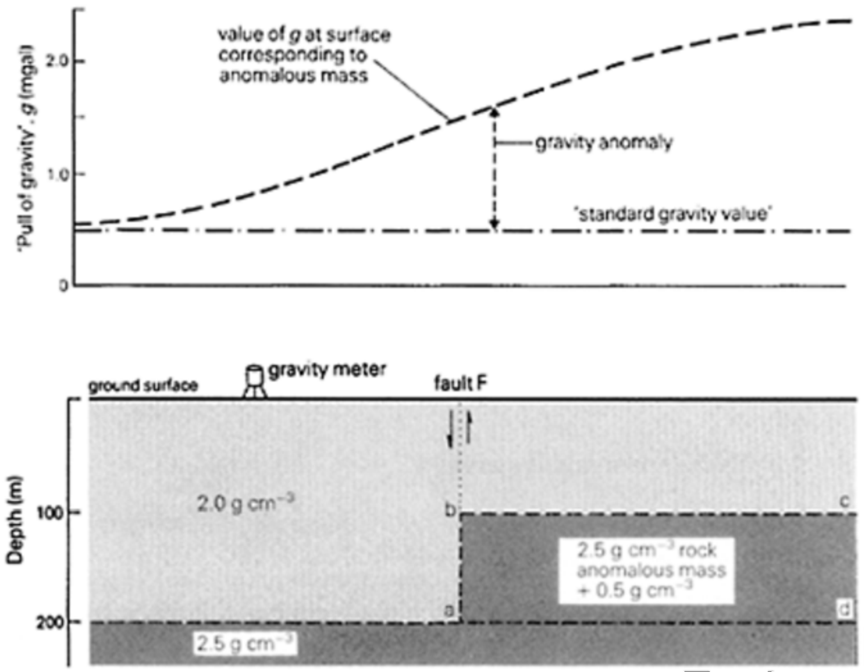


Fig. (4.7). The 'pull of gravity', g, which results from the simple horizontal density layers, is plotted as 'standard gravity value'. The raising of a block of the denser 2.5 g cm^{-3} layer by upthrow along the fault F increases the value of g along the traverse. The greatest increase is on the upthrown side, and the most rapid change of *g* along the traverse (that is, the greatest horizontal gradient of *g*) occurs immediately above the fault. The difference between the second set of values, which include the effects of the anomalous mass, and the 'standard value' at any surface point is called the 'gravity anomaly' at that station. The units used for g are milligals (mgal) .

4.2.6.2 Applications of Gravity Method

1- It is mainly used for regional studies such as that related to earth crust.
2- Delineation of structural contacts and faults.
3- Investigations for minerals and petroleum.
4- Mapping of alluvium- bedrock contact.
5- Gravity investigations of landfill nature and dimensions.

4.2.6.3 Application of Microgravity in Civil Engineering

The term ***microgravity*** denotes an extremely small anomaly occurring in a very small areas. Recording of such anomalies requires a high degree of precision in gravity instruments**.** The unit of this instrument is μgal (= 10^{-6} gal). Nowadays, this method is used in engineering and geotechnical applications.

The main applications of microgravity in civil engineering are:
1- Detection of subsurface voids and cavities.
2- Mapping the ancient buried channels.

3- Finding solutions for problems associated with man-made openings such as abandoned mines and tunnels.
4- For detailed studies for dam sites and detecting groundwater courses.
5- It may be used to study the amount of concrete required for grouting.
6- It is used for archeological studies.
7- Observing and monitoring the changes in earth crust for earthquake prediction.
8- It is used for mineral deposits and petroleum reservoirs.

4.2.7 Magnetic Method

4.2.7.1 Basic Theory

The earth's magnetic field (that is, the ***geomagnetic field***) changes slowly with time, and from place to place. The variation with geographical position includes a gradual change of **magnetic intensity** from about 0.3 oersted (Oe) at the Equator to 0.7Oe at the Poles.

The SI units of magnetic flux density is the tesla (T). The unit commonly used in applied magnetic surveys is the ***gamma*** (1 gamma $=10^{-5}$ Oe). Acute local differences of intensity from the normal background value of a region are called ***magnetic anomalies*,** and are caused by the presence of magnetized rocks in the ground.

Rocks acquired its magnetization from:
1- **Induced Magnetization**: Sedimentary rocks, such as red sandstones, may acquire weaker permanent magnetization during deposition, part or all of the magnetization of a rock may be ***induced*** temporarily by the present field; that is, it would disappear if the rock specimen could be screened magnetically from it. The degree of magnetization in a given intensity of field is related to the ***magnetic susceptibility*** of each mineral in the rock and the ***intensity of magnetic field.***

2- **Remanent Magnetization:** This type of magnetization depends on the geologic history of the rocks. Since a magnetized body has positive and negative magnetic poles, both positive and negative anomalies are produced by the same mass of rock. The shape of the anomaly curve is controlled not only by the shape of the magnetized body but also by the direction in which it is magnetized by the geomagnetic field.

A variety of instruments have been designed to measure different parameters of the geomagnetic field. The most commonly used in site exploration is the ***proton magnetometer*,** which gives the value of intensity at a station to within 1 gamma. A reading can be made in a few seconds and, once the stations are pegged out, a survey can be done rapidly. There is usually no need to level the stations or make systematic corrections to the readings if the survey is over a small area only and is completed in a day. The contoured results (an ***isogram map***) of a survey carried out over an abandoned mineshaft are shown in Figure 4.8. The position of the shaft's rectangular outline is approximate as there is no confirmatory surface feature. The nature of the capping of the shaft, which produces the positive magnetic anomaly, is unknown, but it seems unlikely that iron railings are present. Other anomalies in the geomagnetic field are typical of a colliery yard.

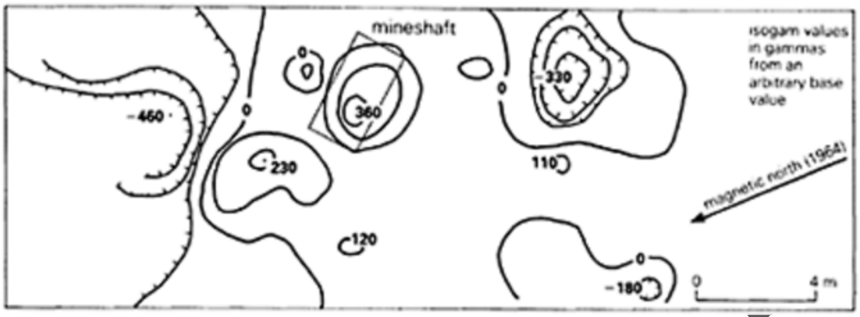


Fig. (4.8). The position of a concealed mineshaft is shown by The rectangle on the map. The magnetic anomalies related to it and to the colliery yard are derived by contouring the readings taken by a proton magnetometer at 100 gamma interval between isogams.

4.2.7.2 Applications of Magnetic Method

1- Magnetic surveys are used mainly for mineral exploration.
2- Magnetic surveys are used to study the structure and composition of the earth.
3- The more general application of the magnetic method is to locate boundaries where igneous rocks lie on one side. It is, for example, the quickest, cheapest and most certain way of locating a dyke close to the surface.
4- It can be useful in indicating the depth to magnetic basement rocks.
5- Detection of archeological objects.
6- It can be used to delineate the area of unconsolidated basin fill or buried river stream-channel aquifers.

REVIEW QUESTIONS AND PROBLEMS

4.1 Why is resistivity as obtained in the field called apparent resistivity?

4.2 Comment on the utility of the electrical resisivity in civil engineering.

4.3 Give short notes for the following items:
- a- Bouguer anomaly
- b- Reflection coefficient
- c- Remanent magnetization
- d- Time intercept
- e- EM method

4.4 Contrast between the following:
- a- Electrical sounding and electrical profiling.
- b- Remanent and induced magnetization.
- c- Geophone and hydrophone.
- d- GPR and seismic reflection.
- e- Gravity and microgravity methods.

4.5 What are the main geophysical methods that are used in civil engineering projects? List their main applications.

4.6 If the travel time curve is a smooth or irregular instead of straight line, What is your inference?

4.7 When do you expect the refraction technique to be non-operative?

4.8 What is the effect of the degree of saturation in the specimen on the wave velocity?

4.9 Compare the velocity values you obtained for the rock specimens with those of the concrete specimens.

4.10 Is it true that ***P*** - waves always travel faster than ***S***-waves ? Can you justify this by equations?

4.11 What is the range values of Poisson' s ratio for rocks? In which (either Field or laboratory) of determination of Poisson' s ratio, are the values for rocks higher and why?

4.12 How does water affect the GPR survey?

4.13 The readings given in Table (4.1) were obtained using a resistivity meter. Complete the table by finding the geometric factor and apparent resistivity .

Table (4.1). Problem 4.13.

MN/2 (m)	AB/2 (m)	Voltage (mV)	Current (mA)	Resistance (ohm)	Factor F $=(\pi/MN)[(AB/2)^2-(MN/2)^2]$	App. Res. ρ_a(ohm.m)
0.15	1.5	53.0	26			
0.15	2.1	20.6	23			
0.15	3.0	11.4	28			
0.15	4.5	3.8	22			
0.75	4.5	17.0	20			
0.75	6.0	13.0	28			
0.75	9.0	7.7	32			
0.75	12.0	3.3	25			
0.75	15.0	2.6	28			

4.14 The following readings (Table 4.2) were obtained using Wenner arrangement during an electrical survey. Complete the table.

Table (4.2). Problem 4.14.

Electrical spacing *a* (m)	Meter Reading *R* (ohm)	Factor *K*	Apparent Resistivity ρ_a (ohm.m)
2	3.3		
4	1.2		
6	0.469		
8	0.311		
10	0.258		
15	0.179		
20	0.163		
25	0.147		
30	0.137		
35	0.135		

4.15 When one face of a slab of rock is struck with a hammer, a detector at the opposite face 85.0 cm away receives waves 230 μm and 425 μm later. Find the velocity of :
a- the S wave and,
b- the P waves in this rock

(Ans. a- 2.0 km/s ; b- 3.70 km/s)

4.16 Certain rocks have density 2.75 gm/cm^3 , Young's modulus 47.4 GPa, and Poisson's ratio 0.413. Calculate the velocity of S waves in the rocks.

(Ans. 2.48 km/s)

4.17 A seismic refraction survey results in data fitting the lines shown on the graph of Figure (4.9). Find the depth to the horizontal interface.

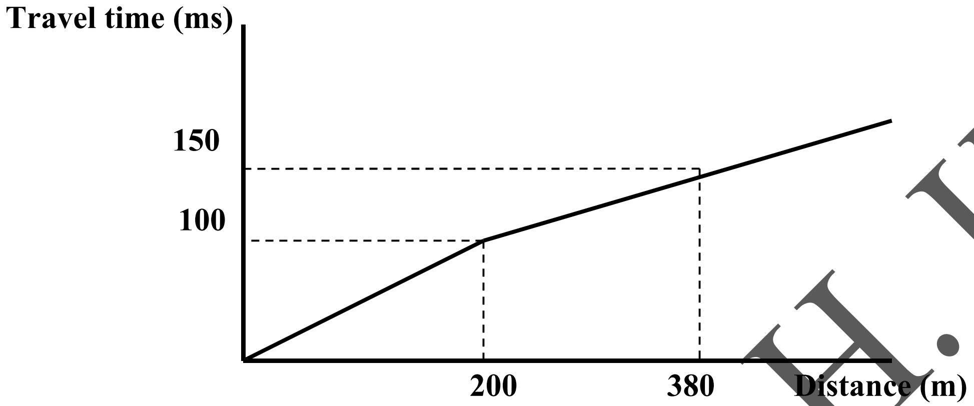


Fig. (4.9) Problem 4.17.

4.18 A particular rock has a shear modulus of 12.6 GPa and seismic wave velocities of 2.25 km/s and 3.87 km/s. Find the bulk modulus of the rock.

(Ans. 20.5 GPa.)

4.19 In a refraction shooting six geophones were placed along a straight line and the seismic record gave the following data (Table.4.3):

Table (4.3). Problem 4.19.

Geophone	Distance from shot point (m)	Time of first arrival (sec)
G_1	100	0.15
G_2	200	0.10
G_3	300	0.15
G_4	400	0.19
G_5	500	0.23
G_6	600	0.28

It is required to:

a- Draw the time-distance graph and how many layers are there?

b- Determine the velocities and

c- Determine thickness of layer(s).

(Ans. a- 2 layers; b- V_1=1943 m/sec, V_2=4000 m/sec; c- Z_1= 104.6 m)

5. Geological Problems Related to Civil Engineering

5.1 Earth Movements

5.1.1 Types of Earth Movements (Down-slope Movements)

There are two main types of down-slope movements as illustrated in Figures (5.1 and 5.2):

1- Slow Movements

It includes:

Creep: It is common on many sloping surfaces. ***Creep*** occurs on steep slopes and produces a downhill movement at low rates (less than 10 mm per year) of the top few meters of soil. It is facilitated by the effects of frost, and by heavy rain washing out fines from the soil. Any excavation on a slope affected by creep is likely to increase movement. Creep may be recognizable by displacement of fencing or of a cover of turf, or by drag effects of strata under the soil. As the rock, including rock fragments, are subjected to continuing erosion and decay, the support under the rock fragments may be so altered that their mechanical equilibrium is disturbed and they move down-slope under the influence of gravity.
Solifluction: It is a special type of slow mass movement. It is defined as the slow flowage down a slope of masses of rock waste saturated with water. It is well developed in permanently frozen ground (***permafrost***).

Indications for Creep and Slide of Soils

1- Bending of trees roots.
2- Bending and slump of columns and walls.
3- Bending and sliding of statues.

Causes of Creep and Slide of Soils

1- The removal and loss of support beneath the rock fragments may be due to many causes such as mechanical movement and disruption and decay of the rock particles under chemical attack.
2- Expansion of rock mass due to freezing of contained water, thus the major component of motion will be normal to the slope. When melting later occurs the released particles will subside again but vertically under the attraction of gravity.
3- Downhill creep of soil and rock fragments due to freezing and thawing.
4- Both rupture by frost and chemical decay may remove support from beneath rock fragments and permits downward movement on a slope.
5- Expansion and contraction in rock masses due to temperature changes.
6- The effect of repeated saturation and drying of water in voids of the unconsolidated materials.

7- The effect of plant roots in causing rock cracks and factures filled by slided soils , the effect of wind, animals and vehicles.

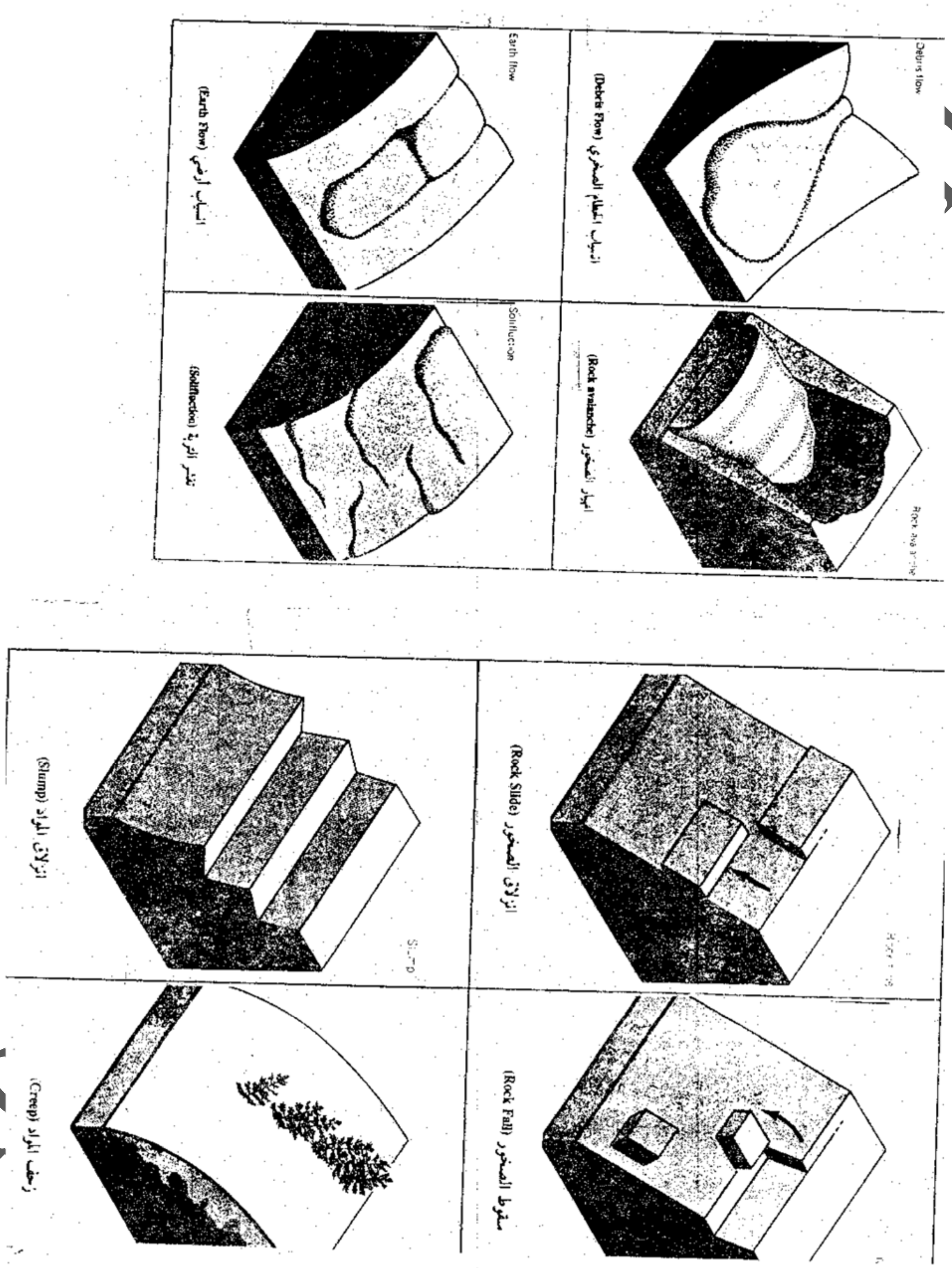


Fig. (5.1) . Types of down-slope movements.

Fig.(5.2). Slope failure at Sonoma County, California.

2- Rapid Movements

Rapid mass movement occur as various kinds of ***slides*** and ***flows***. The basic distinction between them, ***flows*** in which every part of the mass moves with respect to every other part, while in ***slides***, the whole mass moves as a unit by sliding upon a single surface.

a- Flows: ***Flow*** is a rapid movement of waterlogged soil, broken rock and mud down hill, usually after prolonged rain. It involves loss of cohesion in a mass of debris. Specialists in soil mechanics and engineering works use a classification for flows. When large masses of fine material, especially if suddenly saturated, may accumulate on hill-slopes and adjacent valley floors specially in semi-arid regions and are called ***lahr***. When large blocks as well as fine material are involved are called ***debris avalanches*** which are characteristic of mountainous regions.

b- Slides: They move as distinct blocks and may slide upon curved shear surfaces or upon some structural surface such as bedding layers in the rocks. Sliding upon a curved shear surfaces is most common where clays or sands stand in steep walls as in sea cliff, or the bank of rivers, and of artificial cuttings. The sliding characteristics of banks are of immense importance in engineering. Changing the strength of the bank material by removing water (either by installing drains or by planting trees with a high transpiration rate), and so increasing the internal friction, is a method used to stabilize some banks. Examples of banks that were overloaded by surcharging (through building construction) are known from many places, sometimes the results have been disastrous, whole housing developments having slide into a valley.

Rock slides, controlled by the structure of the rock, occur when some potential plane of movement slopes toward an open face and is overloaded. The movement plane may be a fracture, a bedding surface (plane), or any other similar feature.

Minor rock falls are produced by weathering acting on unstable rock slopes. The susceptibility of a given rock to weathering processes can be estimated by determining its saturation moisture content (i_s) and swelling coefficient (E_s). Igneous and high-grade metamorphic rocks with their values of less than 1% are generally safe from weathering effects. Sedimentary rocks and low-grade metamorphic rocks are considered to be safe on slopes if their values are less than 3%. If exposed rocks on a slope have high saturation moisture contents, then tests should be carried out over a period of time, under both freeze-thaw and wet-dry conditions, and their swelling behavior noted. Ice action is important if joints are present. If the rock mass has a low block volume, that is, less than 0.5 m^3, minor rock falls may occur, even if the rock has a low saturation moisture content.

Major rock falls usually result from collapse caused by undermining of rocks above a weak layer. The agent may be weathering, erosion or mining. Common weaknesses in a rock mass which can lead to collapse after weathering and etching out by erosion are layers of clay rock, chlorite in joints, and carbonate rocks, including calcareous sandstones.

Causes of Landslides

The main causes of landslides are:

1- The presence of weak rock layers such as shales or unconsolidated materials such as sands and gravels.
2- The presence of thick and solid rock layers over weak rock layers .
3- The presence of bedding surfaces , joints and steeply dipping faults .
4- The presence of steep rock cliffs.
5- The scarce of vegetation due to high temperature .

Factors Causing Initiation of Movements

1-Supports removal by natural processes (such as waters and wind), or by human–being activities (such as excavation and mining).
2- Increasing weights of rocks due to water saturation.
3- Earthquakes resulted from faulting or volcanoes.
4- Friction decrease between rock masses in the presence of water.
5- Pressures resulted from extension and contraction of water by thawing and freezing respectively.

Subsidence

It is resulted from the slow vertical movement of earth masses due to overloading or weakness of the lower materials. Its causes are:

1- When the positive areas were uplifted, the adjacent areas were depressed.
2- Exploiting groundwater.
3- Destroying the roofs of mines.
4- Dissolution of chemical rocks such as limestones.
5- Compaction due to increase in the weight of rock column.
6- Earthquakes and blasting.

5.1.2 Engineering Aspects of Landslides

Damages and Costs

Highways, railways and pipes are the most common features that are affected by landslides. Also green lands and houses may be destroyed by the effect of landslides. Rivers and lakes may be subjected to such slides as a result of sliding and excavation. For example, as a result of earthquakes, a great damages may be occurred and accompanied by landslides causing many towns to be destroyed. Thus rockslides or landslides are very numerous and usually small. The majority probably involve only a few hundred or a few thousand tonnes of rock and may not even achieve local notice. Some are very large or disastrous and achieve great fame. The largest slide known in Europe is the prehistoric slide at Films, Switzerland, where about 18 cubic kilometers of rock fell off the mountain slide. It dammed the valley of the Rhine to a height of 600 meters. Many other slides were occurred later; such as that occurred in the Pamir Mountains in 1911 that contained 2500 million cubic meters of rock and formed a dam 800 meters high in the Murgab River; and the slide that occurred during 1982-1983 in Yeshtil, USA, that contained about 4 million cubic meter of claystone, sandstone and limestone.

Engineering Solutions

Landslides, rockslides and avalanches present immediate hazards to nearby life and property. Hence, it is usually a serious concern to see it that a local arrangement of earth materials on slopes does not pass from a static to a dynamic state. Engineering intervention may be necessary if the risk of sliding is significant. Thus different stabilizing techniques are introduced by some engineering expedient to avoid slips.

Stabilization of Slopes

In brief, the different common measures taken to prevent slope failure are as follows:

1- Lowering moisture content of soil forming slopes.

2- Lowering groundwater table by drilling deep wells to exploit water.

3- The slope is drained to reduce load and increase strength of frictional forces by means of trenches filled with rubble (fragments).

4- To increase slope stability either the slope is modified by removing material from the potentially active part of the slope ***(load removal***) and adding it to the ***'toe'*** of the slope, or addition of some stabilizing material to the toe of the slope or both processes.

5- When such slopes are nearby life and property (such as highways, railways and buildings), walls construction is recommended. The slope is supported by a retaining wall or by embedded piles which are anchored to the rock mass. The soil and rock behind the wall must be drained.

6- An unstable rock face may be stabilized either by bolting or by using steel mesh. Bolting is used to anchor large unstable blocks, and steel mesh to cover entire sections of an unstable steep rock face. To prevent sliding, stabilization may be done by installation of rock bolts which are solid rods usually of steel driven through the block into the slope and are generally installed at 90˚ to the slope. Where such unstable slopes exist, for example in a new road cutting, sufficient shoulder width should be allowed to "absorb" debris, and a side ditch excavated with or without a rock fence to protect the new road. Another method to prevent sliding is stitch the block to the slope. A hole is drilled through the block perpendicular to, and into the slope. Some cement is poured into the bottom of the hole. Then, instead of a bolt a cable is inserted. One end of the cable is secured by the cement, when hardened.

5.1.3 Prediction and Prevention of Landslides

Most landslides are caused by the gradual deformation of the unconsolidated materials except those resulted abruptly due to earthquakes. To prevent landslides, the previous techniques may be used in addition to other methods suggested by engineers such as electrical osmosis permeability.

Regarding the prediction about the landslides, engineers and geologist usually study the nature of the loose materials and rocks forming the slopes, measure its gradient, nature and distribution of cracks, moisture content of soil and rocks. Some sophisticated instruments may be used to measure the fluid pore pressures. In case of abrupt landslides, there is no signs indicate the possibility of landslide occurrence.

5.2 Principal Geological Factors Affecting Engineering Projects

5.2.1 Stability of Slopes and Cuttings

Geological Factors Affecting the Stability of a New Excavation

The static conditions that control the initial and also the later stability of a steep face cut into soil or rock, and which may determine the need for support or remedial treatment, are as follows:

1- **The properties in bulk,** particularly the **shear strength,** of the material forming the cutting: The stability of a cutting in rock is usually dependent on the occurrence of joints and other planes of weakness, and on the amount of cohesion and the friction across these planes.
2- **The structure** of the rocks and soils, and specifically how any planes of weakness are orientated relative to the newly exposed face: for example, horizontal bedding planes in poorly jointed sandstone often give near vertical faces which are stable, whereas faults or joints striking parallel to the new face, and dipping steeply towards it, will probably be planes of movement or potential instability.
3**- The groundwater conditions:** Saturation significantly lowers the strength of most soils compared with their values when dry. Certain soils weaken to a stage at which they run like viscous liquids. High pore pressure of ground water in a layer, or in a plane of weakness, lowers frictional resistance to movement. (The mechanism is the same as that which allows a hovercraft to glide over water, or land on a high-pressure cushion of air). A dramatic and tragic example of instability triggered by high pore pressure within a body of soils was the Aberfan disaster in 1966, when a spoil heap of mine waste slid downwards on to a Welsh village enveloping and destroying a large part of the local school.
4- **Stresses** produced by natural loads adjacent to the cutting: steep-sided valleys or mounds affect the state of stress in the ground near the surf ace, not only below themselves but also for some distance around. This lateral change in stress conditions may be sufficient to cause instability of weak rocks and soils. For example, valley bulges are produced in this way, and they may be accompanied by instability of an adjacent slope. An initially stable slope may become unstable with the passage of time because of human disturbance. This may consist of adding a fresh load such as a spoil heap, removing support by excavating, or triggering movement by vibrations from nearby heavy machinery.

The other common geological causing instability of existing slopes are:
a**- Weathering** of the soil or rock of the slope so that it becomes weaker: This may affect the bulk of the material (for example, boulder clay) or may be concentrated along planes in a rock. Chemical alteration of existing minerals is

important under certain conditions, as is mechanical break-down in others, Periglacial weathering in Pleistocene times also affects the stability of some present-day cliffs.

b- **Erosion** of the slope by a river or other natural agent, usually at its base but possibly along a weaker layer or plane, may cause undermining to take place.

c- Change in **water content** of the soil or rock: heavy rain, especially after a drought, saturates the material forming the slope, increasing its mass and the gravitational pull on a given volume, and also reducing the strength of soils and the friction along any discontinuities.

5.2.2 Erosion and Deposition

There are different pictures and nomenclature of erosion and deposition processes depending upon the type of transporting agent whether it is water, wind or ice. Thus, there are:

1- Erosion and deposition by water.
2- Erosion and deposition by wind.
3 Erosion and deposition by ice.

5.2.2.1 Erosion and Deposition by Water

Rivers do not ordinarily flow in straight lines very long. Small irregularities in the channel cause local fluctuations in velocity, which result in a little erosion where the water flows strongly against the slide of the channel and some deposition of sediment where it shows down a bit. ***Bends***, or ***meanders***, thus begin to form in the river. Once a meander forms, it tends to enlarge and also to shift downstream. It is eroded on the outside and downstream side of the meander, the ***cut bank***, where the water flows somewhat faster (and the channel, too, tends to be a little deeper there as a result); ***point bars***, consisting of sediment deposited on the insides of meanders, build out the banks in those parts of the channel. The rates of lateral movement of meanders can range up to tens or even hundreds of meters per year, although rates below 10 meters/year are more common on smaller rivers.

Obstacles or irregularities in the channel may slow flow enough to cause localized sediment there. Over a period of time, if the sediment load of the river is large, these channel islands can build up until they reach the surface, effectively dividing the channel in a process called ***braiding***. If the braided river may develop a complex pattern of many channels that divide and rejoin, shifting across expanse of sediment.

Over a period of time, the combined effects of erosion on the cut banks and deposition of point bars on the inside banks of meanders, and downstream meander migration, together produce a broad, fairly flat expanse of land covered with sediment around channel proper. This is river's ***floodplain***, which in the area into which the river spills over during floods. Sediment deposition during floods can, be an important additional factor contributing to the formation of this flat area surrounding the channel. The floodplain, then is a normal product of river evolution over time.

Meanders do not broaden or enlarge indefinitely. Very large meanders represent major detours for the flowing river. At times of higher discharge, especially during floods, the river may make a shortcut, or ***cut off*** a meander, abandoning the old, twisted channel for a more direct downstream route. The cut off meanders are called ***oxbows***. These abandoned channels may be left dry, or they may be filled with standing water, making ***oxbow lakes***.

Regarding deposition, variations in river's velocity along its length are reflected in the sediments deposited at different points as illustrated in Figure (5.3). The more rapidly a river flows, the larger and denser are the particles moved. The sediments found motionless in a river bed at any point are those too big or heavy for that river to move at that point. Where the river flows quickly, it carries gravel and even boulders along with the finer sediments. As the river slows down, it starts dropping the heaviest, largest particles-the boulders and gravel-and continues to move the lighter, finer materials along. If river velocity continues to decrease, successively smaller particles are dropped: the sand-sized particles next, then the clay-sized ones. In a very slowly flowing river, only the finest sediments and dissolved materials are still being carried. If a river flows into a body of standing water, like a lake or ocean, the river's flow velocity drops to zero, and all the remaining suspended sediment is carried.

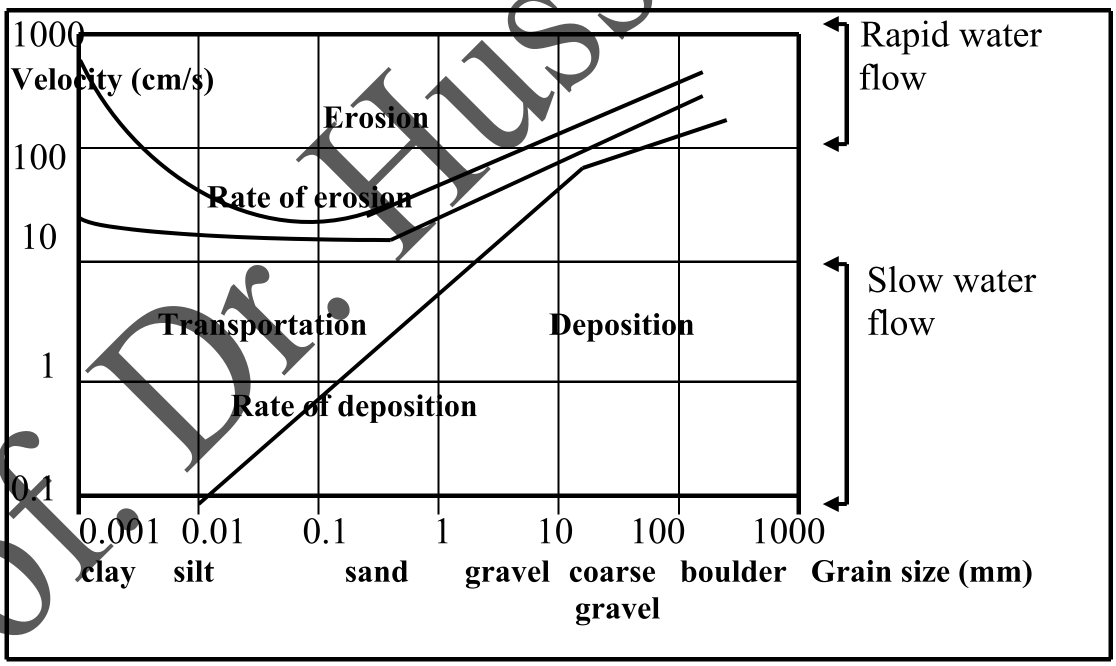


Fig. (5.3). The relation between erosion and deposition in running water.

The relationship between the velocity of water flow and the size of particles moved accounts for one characteristic of river-deposited sediments: They are ***well sorted*** by size or density, with materials deposited at a given point tending to be similar in size or weight. If the river is still carrying a substantial load as it reaches its mouth, and it then flows into still waters, a large, fan-shaped pile of sediment, a delta, may be built up. A similarly shaped feature, an ***alluvial fan***, is formed when a tributary river flows into a more slowly flowing, larger river, or a river flows from mountains into a plain.

An additional factor controlling the particle size of river sediments is physical breakup and/or dissolution of the sediments during transport. That is, the farther the sediments travel, the longer they are subjected to collision and dissolution, and the finer they tend to become. River-transported sediments may thus tend, overall, to become finer downstream, whether or not stream's velocity changes along its length.

It is seen that navigable rivers are of great importance to people. We depend upon rivers for energy, travel, and irrigation. Civil engineer plays a central role in the design, construction and maintenance of navigable inland waterways. Many of these activities demand engineering judgment reinforced by an ability to use the tools of hydraulics and the theory of model.

Any effort to regulate or control the flow of natural streams should begin with an understanding of the forces in the river development. The power exercised by a river originates in the potential energy of its tributaries. Water flowing downstream consumes this energy in its own transportation against the resistance of the bed and banks which confine the flow. Soil eroded in this process is used by the river as a grinding powder to fasten the rate of downstream erosion. The deepening channel becomes a more efficient conduit for the growing stream, and the resulting increase in velocity accelerates the process of channel cutting.

5.2.2.2 Erosion and Deposition by Wind

A strong wind blowing across rock debris or soil can lift and carry fine material as dust, and can move the larger sand grains by rolling them and making them bounce across the surface. This windborne movement of material occurs in areas with little or no vegetation and is typical of hot desert regions, although the process also operates in cold deserts and some coastal areas. Wind both transports and sorts the material. The finer, silt-sized fraction is carried in suspension by the wind, and may travel great distances before it is eventually deposited as ***loess***. The coarser material that remains forms ***sand dunes***. Both loess and sand dunes are liable to further erosion by wind unless their surface is stabilized by vegetation or another binding agent. They are composed mainly of quartz with a smaller fraction of other stable minerals such as iron oxides. Near coasts calcite in the form of shell debris may occur occasionally. Clay minerals are virtually absent.

Erosion and transport by wind are most important in desert regions, which lack a protective cover of vegetation and a skin of surface water to bind the grains together. Conditions favoring the formation of ***aeolian deposits*** were, however, more widespread in the present temperate zones during and immediately after the Great Ice Age, which ended approximately 10000 years ago. For example, lowered sea levels at certain times left broad stretches of beach sand exposed to wind action, and assisted the formation of sand dunes along many British coasts. In other regions that were free, or freed, of ice and temporarily devoid of plants, the deposits left by the retreating ice, together with other soils, provided sources of loess.

5.2.2.3 Erosion and Deposition by Ice

Erosion by ice, and deposition of superficial deposits from it, are processes limited geographically at the present day to arctic regions and to very high mountains. There are two important ways by which moving ice can erode:

a- It adheres to rock surfaces, and if a block can be detached easily along minor fractures in the rock, the moving ice plucks it from the outcrop, especially if the outcrop is on the downstream side of a rocky obstruction. The blocks, which are incorporated into the base of the glacier, are usually less than 1 m across, but there are cases where plucking has detached great slices of bedrock sufficiently large to appear to be still in place, until deeper boring showed boulder clay below them. Plucking by ice does not always detach blocks, but may simply open up minor fractures near the surface.

b- The rock fragments embedded in the base of the glacier become cutting tools as it grinds forwards. They make scratches on the solid rock surface called ***glacial striae (or striations)***) (Fig. 5.4), and may polish parts of the bedrock surface to a high glaze. Any minor projection of solid rock in the ice's path is ground away, and larger obstructions become streamlined in the direction of ice flow. In the process, the rock fragments themselves become abraded, and part is eventually crushed to fine rock powder, consisting of unweathered minerals. Deposition from ice, on high ground, glaciers suffer no appreciable wastage and can add to their load of ***moraine***. In these areas of glacial erosion, the cover of drift left when the ice melts is thin and consists mainly of glacial sands, gravels and layered clays. At lower altitudes, a glacier is burdened increasingly with moraine, yet, as the ice wastes, it is less able to transport it. Most ***till*** is deposited from the bottom of the ice sheet while it is still flowing. The movement sometimes moulds the till into streamlined low hills called ***drumlins***. The composition of the till is determined by the nature of the rocks cropping out up stream from where it was deposited.

Fig. (5.4). A glaciated rock surface which has been smoothed and Moulded into a streamlined form by ice. The superficial scratches on the rock surface are glacial striae. The deeper, more prominent, cracks along which the rock is broken are small joints.

5.2.3 Groundwater

As mentioned above, There are other problems related to civil engineering especially those related to groundwater level which represent a serious problems facing a civil engineer during construction large structures such as dams, reservoirs, tunnels, and foundations. Besides, the geologic structures affect the levels of the groundwater table.

For a tunnel driven through syncline, with the presence of groundwater, the water seepage will be towards the tunnel, and water may accumulate in the tunnel. But, if a tunnel is driven through an anticline, the water seepage will be outside the tunnel. Hence for tunnels constructed in water-bearing layers below groundwater table, it requires some remedies such as grouting with cements or lowering water table by pumping. Using the type of remedy method depends on the porosity, permeability, applied pressure and finally the presence of joints and their orientations especially in calcareous rocks such as limestone. That is because these joints become soluble channels or caves.

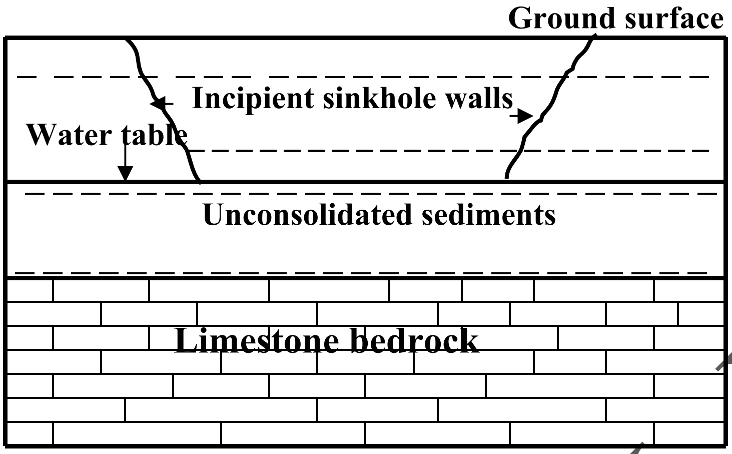
Karst Formation

karst is a unique geomorphic landscape is formed by dissolution of soluble rocks. In most areas the development of landforms is a result of mechanical erosion and tectonic uplift. In karst areas mechanical erosion plays a much smaller role and it is the dissolution of soluble rocks- primarily carbonate rocks such as limestone and dolomite but in restricted areas also gypsum, anhydrite, and rock salt- that is the most important agent of erosion. Karst develops by dissolution of soluble rocks with a resulting land surface characterized by sinks or sinkholes, disappearing streams (with the result that there is little or no surface drainage system), underground passageways (***caves***) and stream systems, and residual hills that represent the remnants of soluble rocks in which dissolution process is not yet complete. The areas where karst is best developed have carbonate rocks and an ample supply of CO_2 and water. The result is that in arid and semiarid regions karst is uncommon.

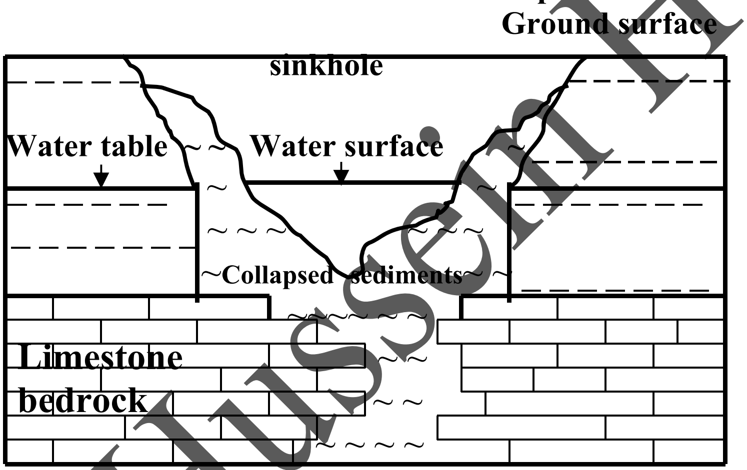
The formation of caves and caverns in the subsurface is the result of the movement of acidic waters through the carbonate bedrock and the dissolution of the bedrock. The source of water is either groundwater percolating downward into bedrock or surface water carried into the underground drainage systems by streams that enter the system, often in the form of disappearing streams. Sulfuric acid produced in the subsurface apparently formed caverns and associated caves. The acid was produced by the mixing of H_2S that had moved into the area with the groundwater. The acid dissolved the limestone and the material were carried away in solution.

Sinkholes Formation

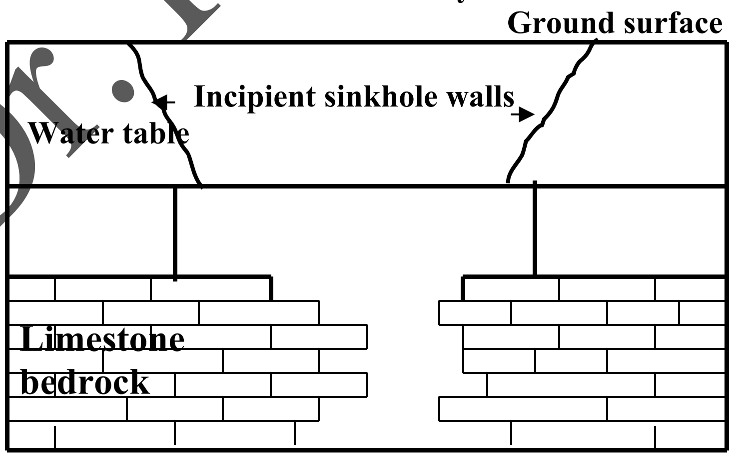
The progressive downward movement of unconsolidated materials into underground limestone opening naturally affect the surface of the land and produce funnel-shape sinkholes at the land surface. Thus, the subsidence of part of the earth's surface when sinkhole occurs in an urbanized area, considerable property damage results. Human-made structures collapse, sewer lines are ruptured, and underground utility lines (gas, pipelines, electric cables, telephones lines, etc.) are left hanging or are severed. Figure (5.5) shows geologic cross-sections stages for the formation of a sinkhole.



a- Geologic cross section of sinkhole area before collapse occurred.



b- Geologic cross section of sinkhole immediately after sinkhole was formed.



c- Geologic cross section of sinkhole area immediately before collapse.

Fig. (5.5). Sinkhole formation.

5.2.4 Effect of Geological Structures on Engineering Projects

All rock masses suffer from several defects or discontinuities which could be in genesis (origin) or after being deposited. Besides, these defects may be of ***macroscale*** or ***microscale***. Macroscale due to the forces acting within the earth (***epirogenic***, continental building movements or ***orogenic***, mountain building movements). Microscale is the property of the rock substance.

Defects in rocks may be grouped as follows:

1- Fractures, cracks.
2- Fissures.
3- Bedding planes, lamination, schistosity, partings.
4- Stratifications.
5- Joints.
6- Fault planes and zones, crushed zones.
7- Folds.
8- Voids.
9- Cavities and karst.
10- Seams and interbeds of weak and plastically unstable rocks, aquifers, clays and shales.
11- Ancient slip planes and other possible weakness.

All the above defects affect the bulk properties of rocks and hence the construction of the engineering projects. In the next sections we will discuss the effects of joints, faults and folds. Planes and zones of weakness in rocks are classified as existing and/or potential ones. Thus, the main types of fractures are joints and faults.

5.2.4.1 Effect of Joints on Engineering Projects

Where displacement, usually of a few centimeters, of the broken rock has taken place at right angles to the plane of fracture (Fig. 5.6), it produces a ***tension fracture***. More commonly, at depths where tension is only relative and where rocks are brittle or semi-ductile, failure takes place along ***shear fractures***. Minor fractures in rocks, both tensional and shear, are called ***joints***.

The presence of faults and joints is important to nearly all fields of economic geology. Joints, if frequent, have a considerable effect on the bulk properties of a rock mass. There is more difference in mechanical properties between a massive granite and a well jointed granite than between a massive granite and a massive gabbro. Joints affect the strength and stability of the rock mass, and the voids associated with their presence allow increased circulation of ground water through them. This may be relevant in water supply, in drainage of a deep excavation or in leakage through the sides or floor of a reservoir. Faults have similar effects on rocks, but are concentrated zones of weakness and of percolation, which may receive local remedial treatment in engineering works. Analysis of the geometry of fractures is advisable in most construction projects, for example: where excavation can take advantage of planes of weakness; where rock bolts or other strengthening devices can be placed and orientated to be most effective; where design of major structures, such as dams, should be modified to avoid placing the maximum stress parallel to a plane of weakness; or where grouting has to be done to seal fractures against leakage. This latter is best achieved by drilling holes perpendicular to the fractures.

Fig. (5.6). Layers of sandstone and conglomerate cut by small faults and joints (some of which are small shears) similar, apart from magnitude of displacement, to the faults.

Joints system have attracted the attention of builders ever since rock was used in engineering structures as a structure-supporting material. In underground openings, joints affect the extent to which their sides, walls, and roof must be supported. Joints respond to explosions, applied static and dynamic loads and seepage of water. Because joints are one of the major causes of excessive overbreak of rock excavations and because joints constitute potential rock-slide hazards in unlined, undercut rock formations, and create water trouble in rock excavations, jointing always deserves careful attention and careful exploration.

5.2.4.2 Effect of Faults on Engineering Projects

Faults are fractures along which there has been some displacement. Faults are named and classified according to inclination of the fault plane and by the direction and relative movements of the rocks along the fault plane. Faults may be:

1- Active or live faults: Those are along which movement has occurred sporadically during historical time. Earthquakes are caused by movement along active faults.

2- Inactive or passive or dead faults: Those are in which no movement has occurred during historical time.

A fault sets in where the continuity of rock (or soil) layers is interrupted by failure in shear of the rock due to compressive forces when the rock is strained past the breaking point and yield along a crack or series of cracks, so that corresponding points on the two sides become distantly offset (Fig.5.7). One side of the so-sheared rock mass may rise or sink, or more laterally with respect to the other, depending on the nature of disturbance.

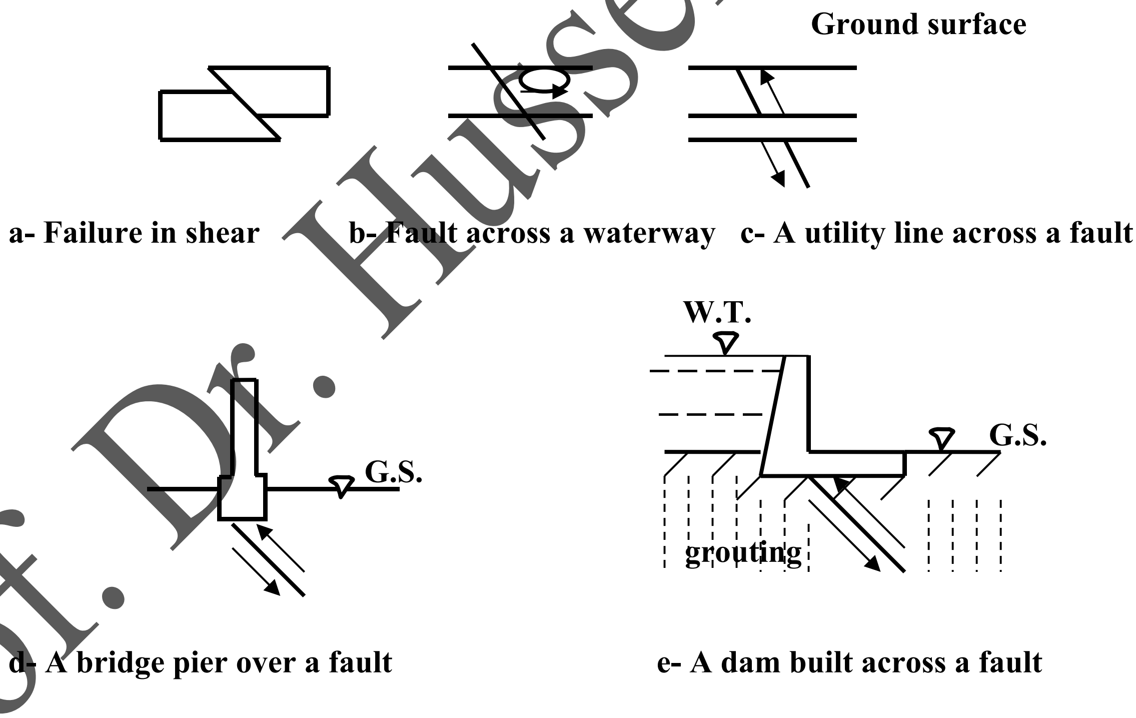


Fig. (5.7). Structures across faults.

Faults may be vertical, horizontal, or in the direction of dip (dip slip fault), or in the direction of strike (strike slip fault).

Generally faults may be classified as:

1- Normal faults: When the hanging wall (H.W) side appear to have moved relatively downwards with respect to the adjoining foot wall (F.W) side. Usually the dip of fault plane more than 45◦ (Fig. 5.8).

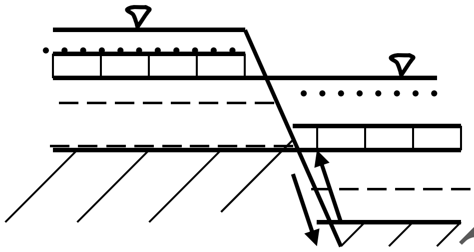


Fig.(5.8). A normal fault.

2- Reverse faults: When the foot wall side appear to have moved relatively downwards with respect to the adjoining hanging wall. The H.W appears to have risen and the dip of fault plane is usually less than 45° (Fig.5.9).

Fig.(5.9). A reverse fault.

For important engineering structures, careful studies must be done.

1- If a bridge foundation is put over a fault (Fig.5.10), there is a chance of sinking of the bridge pier due to superstructure load.

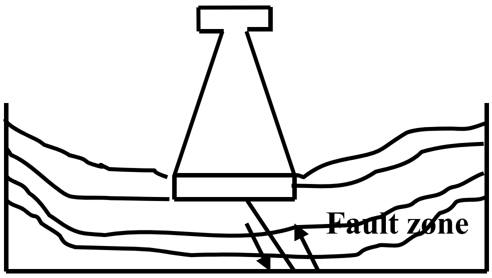


Fig. (5.10). A bridge foundation is over a fault.

2- Similarly, if a masonry dam is put on a faulted zone (Fig. 5.11), there is a chance of danger due to structure as sliding might take place due to the resultant force (***R***). In such cases, foundation bed is improved by grouting.

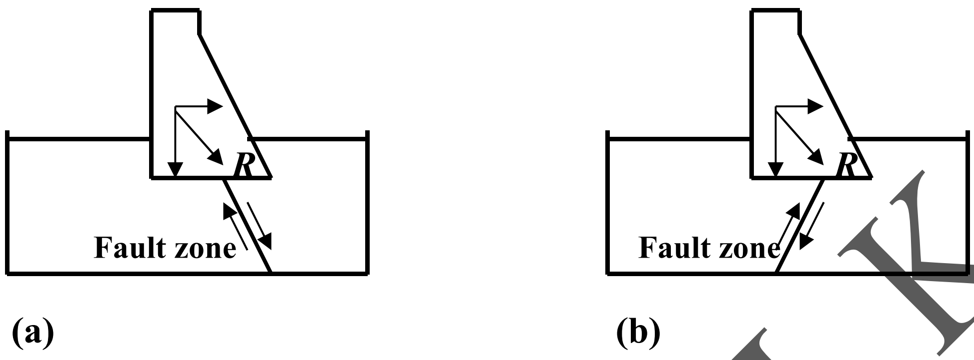


Fig. (5.11). Masonry dam is built on fault zone.

From above Figure (5.11), it is obvious that the location of the fault zone is dangerous in case (a) as the resultant force is in the same direction of the fault zone.

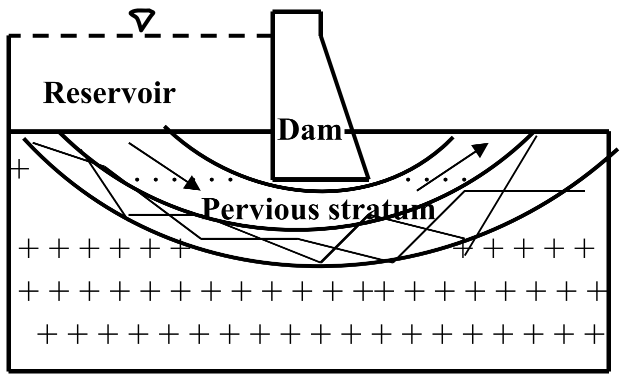
3- In seismic regions, faults give rise to an additional risks and problems, namely when built across faults, and structures such as tunnels, dams, bridges and pipelines may experience. Hence, in geotechnical engineering, faults constitute an undesirable hazard in working in rocks.

5.2.4.3 Effect of Folds on Engineering Projects

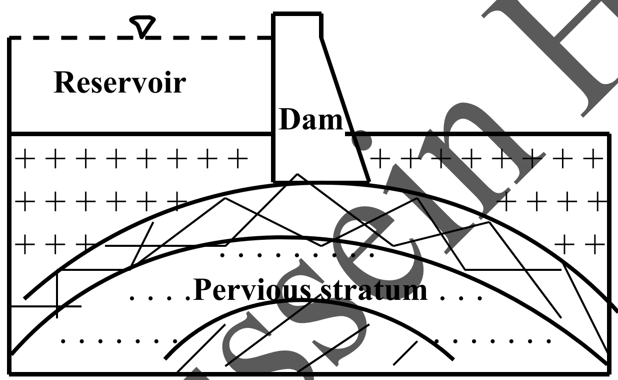
Folds have a great effect on engineering structures, thus in the construction of any project we must have information about the geologic nature of the area including the lithological composition, how these rocks are distributed over, and under, the site (that is, their structure); the frequency and orientation of joints in the different bodies of rock and the location of any faults. Besides, knowing the kinds of folds and their rock type, porous or nonporous-pervious or impervious, is very important because the presence of such structures and rocks will affect the project site (dam, reservoir, and tunnel).

In the construction a dam and reservoir on syncline rock layers (Fig. 5.12a), and one of these layers is sandstone which is porous and permeable rocks, in this case a seepage of water may occur through this porous layer and consequently the dam may be subjected to subsidence.

If the dam and reservoir are constructed on an anticline rock layers (Fig. 5.12b), in this case, the seepage of water through such layer will not affect the dam site as the water seepage will be outside.



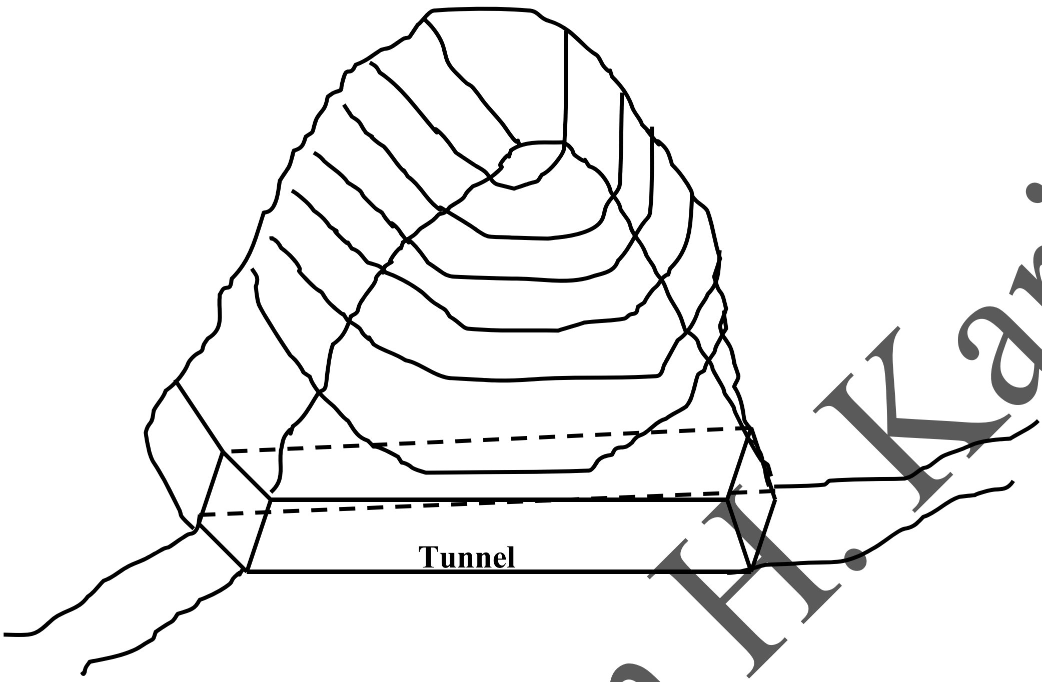
a- The presence of pervious layer in syncline layers.



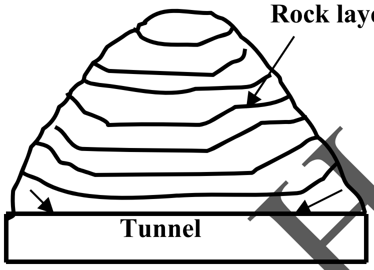
b- The presence of pervious layer in an anticline layers.

Fig. (5.12). A dam constructed on a syncline and an anticline rock layers.

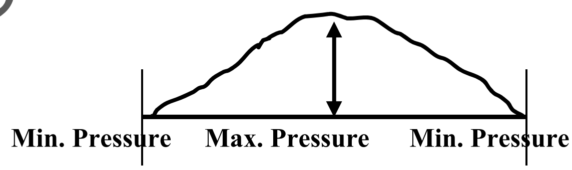
If the alignment of a tunnel is traced normal to the strike under an anticline or syncline of a folded rock system, there is variation in rock pressure (***P***) on the tunnel from above rock masses. For a tunnel driven through syncline (Fig. 5.13), large rock pressures are imparted in the middle part of the tunnel, while the minimum pressures at both ends of the tunnel. Thus, the water seepage will be towards the tunnel, and water may accumulate in the tunnel. Hence, the large pressures in the rock strata transmitted to the tunnel may complicate the driving and construction of the tunnel technically as well as economically. Also, large quantities of water may accumulate in syncline.



(a) A tunnel driven in a syncline layers.



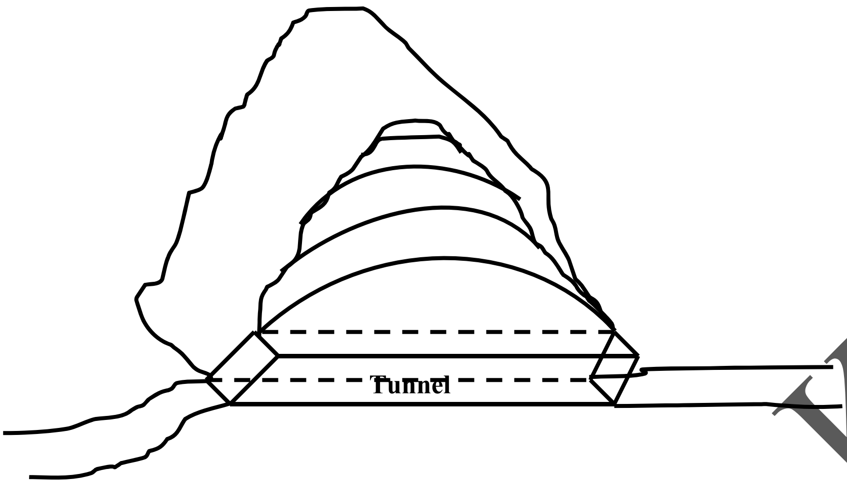
(b) A cross section.



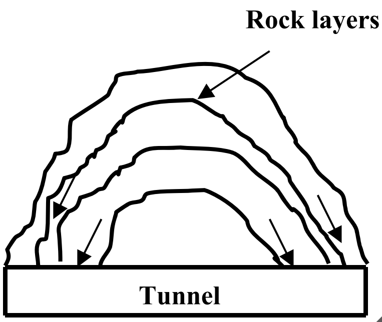
(c) Pressure distribution in the tunnel.

Fig. (5.13). A tunnel driven in a syncline.

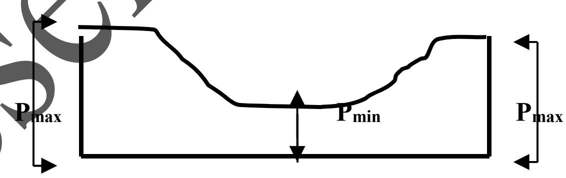
If a tunnel is driven through an anticline (Fig. 5.14), notice the arching effect of the convexly curved rock stratification on the magnitude of pressure at the ends (basis) of the arch at both ends and at the middle of the tunnel. Hence, the maximum pressures are concentrated in the both ends of the tunnel while the minimum pressures at the middle of the tunnel. Thus, the water seepage will be outside the tunnel.



a- A tunnel driven in an anticline layers.



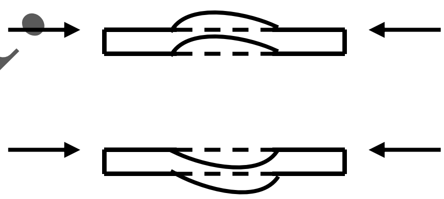
b- A cross section.



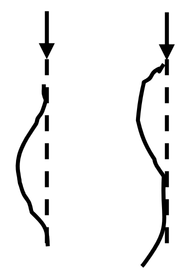
c- Pressure distribution in the tunnel.

Fig. (5.14). A tunnel driven in an anticline.

Folds result from forces acting tangentially to the earth surface (Fig. 12.15). The folds may assume a wide variety of shapes. An upwarped segment of earth crust is an anticline. A downwarped segment is a syncline.



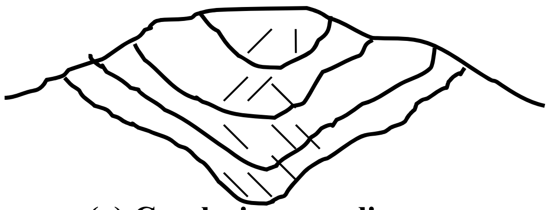
(a) Folding of a rock strata



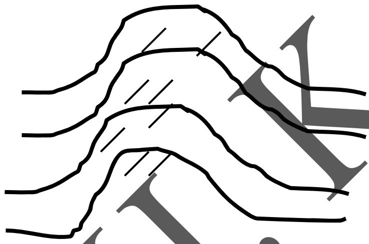
(b) Buckling of columns

Fig. (5.15). Formation of folds.

In geotechnical engineering, the synclines may cause problems of water accumulation. Also, rock folding is usually accompanied by fissures in anticlines and synclines. Along the crest of anticlines, tension cracks are usually formed where rock strata are under tension. In synclines, the lower rock strata are under tension, hence the cracks at the bottom (Fig. 5.16).



(a) Cracks in a syncline



(b) Cracks in an anticline

Fig. (5. 16). Cracks in folds.

5.3 Volcanoes

5.3.1 Introduction

Successive eruptions from a central vent result in a mountainous accumulation of material known as a **volcano**. When fluid lava leaves a conduit, it is often stored in the crater until it overflows. However, lava does not always issue from a central crater. Sometimes it is easier for the magma or escaping gases to push through fissures on the volcanoe's flanks. The eruptive history of each volcano is unique; consequently, all volcanoes are somewhat different in form and size. Nevertheless, volcanologists have recognized that volcanoes exhibiting somewhat similar eruptive styles can be grouped.

Many people assume that lava is the principal hazard presented by a volcano. Actually, lava generally is not life-threatening. Most lava flows advance at speed of only a few kilometers an hour or less, so one can evade the advancing lava readily even on foot. The lava will, of course, destroy or bury any property over which it flows. Lavas, like all liquids, flow downhill, so one way to protect property is simply not to build close to the slopes of the volcano. Throughout history, however, people have built on or near volcanoes, for many reasons. They may simply not expect the volcano to erupt again (a common mistake even today). Also, soil formed from the weathering of volcanic rock may be very fertile.

Most volcanic activity is concentrated near plate boundaries. Volcanoes differ in eruptive style in the kinds of dangers they present. The theory of ***plate tectonics*** holds that the outer rigid ***lithosphere*** consists of about twenty rigid segments called plates. Of these, the largest is the Pacific plate. The lithosphere overlies a zone of much weaker and hotter material known as the ***asthenoshpere***. One of the main tenets of the plate tectonics theory is that each plate moves as a distinct unit in relation to other plates. As the plates move, the distance between any two places is continually changing as they are located on different plates. Since each plate moves as a distinct unit, all major interactions between plates occur along plates boundaries (Fig.5.17). Thus, most of the earths seismic activity, volcanism, and mountain building occur along these dynamic margins. For some time now, tectonic activity has been known to be restricted to narrow zones, such as the so-called ***Ring of Fire*** that encircles the Pacific. Thus, the first approximations of plate margins relied on the distribution of earthquakes and volcanic activity.

In terms of their activity, volcanoes are divided into three categories; active; dormant, "or sleeping"; and extinct, "or dead". A volcano is generally considered ***active*** if it has erupted within recent history. When the volcano has not erupted recently but is fresh-looking and not too eroded or worn down, it is regarded as ***dormant***: inactive for the present but with the potential to become active again. Historically, a volcano that has no recent eruptive history and appears very much eroded has been considered ***extinct***, or very unlikely to erupt again.

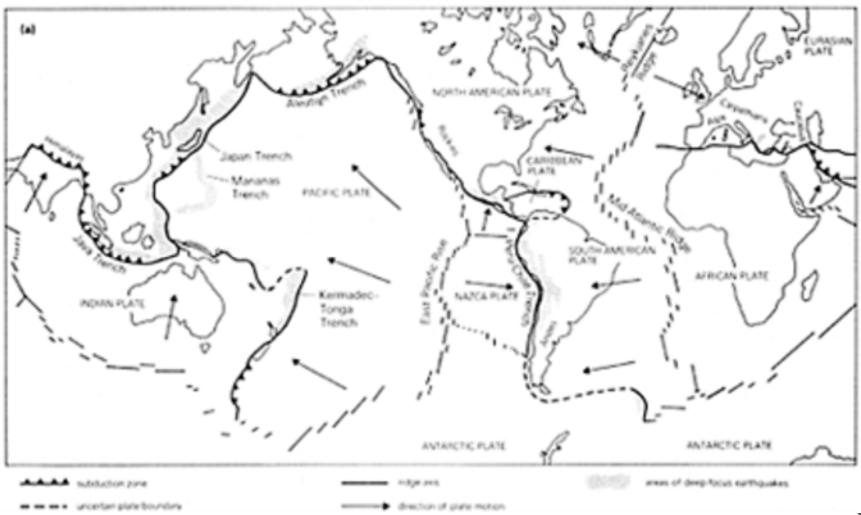


Fig. (5.17). Location and boundaries of the major lithospheric plates of the Earth, showing relative motion by means of arrows.

5.3.2 Prediction Volcanic Activity

Volcanologists can detect the early signs that a volcano may erupt in the near future, but they cannot predict the exact timing or type of eruption. The first step in predicting volcanic eruptions is monitoring, keeping an instrumental eye on the volcano. There are an estimated 300 to 500 active volcanoes in the world. What do scientists look for when monitoring a volcano?

1- One common advance warning of volcanic activity is seismic activity (earthquakes).
2- The rising of a volume of magma and gas up through the lithosphere beneath a volcano puts stress on the rocks of the lithosphere, and the process may produce months of small (and occasionally large) earthquakes.
3- Bulging, tilt, or uplift of the volcano's surface is also a warning sign. It often indicates the presence of a rising magma mass, the buildup of gas pressure, or both.
4- Other possible predictors of volcanic eruptions are being evaluated. Changes in the mix of gases coming out of a volcano may give clues to impending eruptions; SO_2 content of the escaping gas shows promise as a precursor, perhaps because more SO_2 can escape as magma nears the surface.
5- Surveys of surface temperatures may reveal especially warm areas where magma is particularly close to the surface and about to break through.
6- Magnetic measurements over the area of volcano, especially as the temperature of magma increases above Curie point it losses its magnetism.

7- As with earthquakes, there have been reports that volcanic eruptions have been sensed by animals, which have behaved strangely for some hours or days before the event. Perhaps animals are sensitive to some changes in the earth that scientists have not thought to measure.
8- The knowledge of a volcano's eruptive history allows anticipation of the general nature of eruptions and of the likelihood of renewed activity in the year future.

5.3.3 Reduction of Hazards Related to Volcanoes

Lava flows may be hazardous to property, but in one sense, they are at least predictable: like other fluids, they flow downhill. Their possible flow paths can be anticipated, and once they flowed into a relatively flat area, they tend to stop. Where it is not practical to arrest the lava flow altogether, some efforts may be succeeded such as:

1- It may be possible to divert the lava flow from an area in which a great deal of damage may be done to an area where less valuable property is at risk.
2- Sometimes, the motion of a lava is slowed temporarily during an eruption because the volcano's output has lessened or because the flow has encountered a natural or artificial barrier.
3- The magma contained within the solid crust of the flow remains molten for days, weeks, or sometimes months. If a hole is then punched in this crust by explosives, the remaining fluid magma inside can flow out and away. Careful placement of the explosives can divert the flow in a chosen direction.

5.4 Earthquakes

5.4.1 Introduction

The global distribution patterns of ***earthquakes*** and their depths of origin were known before ideas on plate tectonics were formulated. Earthquake activity patterns were determined by ***seismology*** studies, and major earthquake zones were identified around the Pacific Ocean, along the Alpine-Himalayan belt, on mid-ocean ridges, at trenches and in young fold mountain belts. A seismicity map for the Earth in the 1960s is shown in Figure (5.18), which demonstrates that seismicity is concentrated along plate boundaries (compare with above Fig. 5.17).

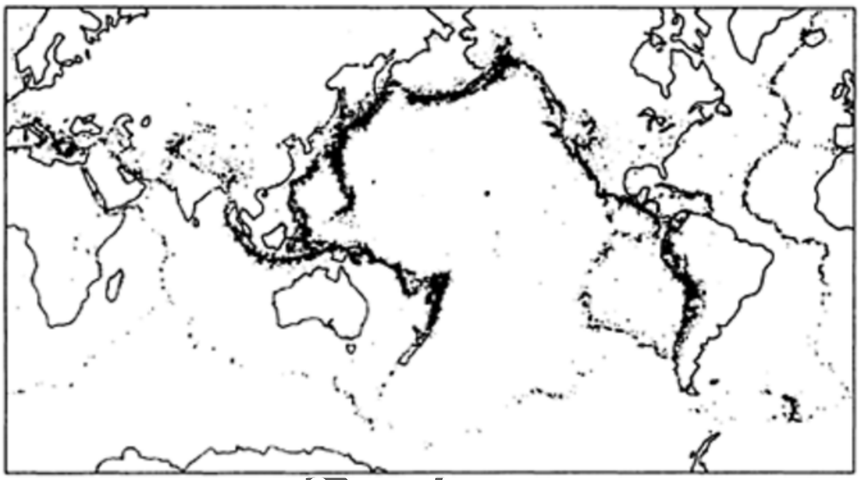


Fig. (5.18). Distribution of earthquake epicenters on the Earth for the period 1961–1967.

An ***earthquake*** is the vibration of the earth produced by the rapid release of energy in the lithosphere which dramatically demonstrate that the earth is a dynamic, changing system. Earthquakes occur along active faults and sometimes, the stress produces new faults or breaks; sometimes, it causes slipping along old, existing faults. Seismic waves are generated when there is a sudden release of energy because rocks which have been strained elastically suddenly fail and move. Seismic waves can be detected by an instrument called a ***seismograph***, and the record produced by a seismograph is called a ***seismogram***. The centre at which this happens, and from which waves are transmitted in all directions, is called the ***focus***. This energy radiates in all directions form its source, the ***focus*** or ***hypocenter***, in the form of waves analogous to those produced when a bell is struck, vibrating the air around it. The focus or hypocenter represents the point on the fault at which the first movement or break occurs during an earthquake. Most earthquakes are with focal depths between 70-700 km. The position on the earth's surface directly above (vertically) the focus is called the ***epicenter***. Earthquakes are subdivided according to its focal depth into two types:

a- Shallow-Focus Earthquakes: These have focal depths below 100 km. They are concentrated at ocean ridges and transform faults, and occur at depths of less than 30 km.

b- Deep-Focus Earthquakes: These have focal depths above 100 km. Deep earthquakes occur in zones beneath the oceanic trenches, with the foci located at varying depths along the subduction zone, which extends downwards to depths of more than 250 km. The deepest earthquakes have been recorded from active island-arc systems.

Also, earthquakes are classified into:

1- Natural Earthquakes: Those are occurred naturally and subdivided into:

a- Earthquakes resulted from volcanic eruptions.

b- Earthquakes resulted from movements in the earth crust, excluding volcanic eruptions, such as crustal uplifting and subsidence, internal rock slides and faulting.

2- Artificial Earthquakes: They are resulted from fluid injection in oil wells which might release all the stresses at once resulting in a major damaging earthquake. One of the dangerous earthquakes those are resulted from nuclear explosions beneath earth surface and at the bottom of the oceans. Besides, the ***microearthquakes*** resulted from the artificial lakes of dams. Other sources of artificial ground vibrations include:

a- Machine foundation vibrations.

b- Vibrations resulted from traffic (vehicles movement).

c- Vibrations resulted from impacts (such as buildings destruction, ram works, compaction, piling, and explosions).

5.4.2 What Mechanism Does Produce a Destructive Earthquake?

Ample evidence exists that the earth is not a static planet. Numerous ancient wave-cut benches can be found many meters above the level of the highest tides, which indicates crustal uplifting of comparable magnitude. Other regions exhibits evidence of extensive subsidence. In addition to these vertical displacements, offsets in fence lines, roads, and other structures indicate that horizontal movements are frequently associated with large fractures in the earth called faults. Although most of the displacement along the fracture occurred in this rather short period , additional movements and adjustments in the rocks occurred for several days following the main quake. The adjustments that follow a major earthquake often generate smaller earthquakes called ***aftershocks.*** Although these aftershocks are usually much weaker than the main earthquake, they can sometimes cause significant destruction to already badly weakened structures. In addition, small earthquake called ***foreshocks*** often precede a major earthquake by days or in some cases by as such as several years. Monitoring of these foreshocks has been used as a means of predicting forthcoming major earthquakes.

Magnitude of an Earthquake

The ***magnitude (M)*** of an earthquake is a measure of the size of an earthquake, based on the amplitude of elastic waves it generates. Thus, the magnitude of an earthquake is a measure of the energy generated at its focus. A scale of magnitude is a way of classifying earthquakes according to their ***potential*** destructive power. The tremendous energy released by atomic explosions or by volcanic eruptions can produce an earthquake, but these events are usually weak and infrequent.

Early attempts to establish the intensity of earthquakes relied heavily on subjective descriptions. Many factors , including distance from epicenter, nature of surface materials, and building design, cause variations in the amount of damage. Consequently, methods were devised to determine the total amount of energy released during an earthquake, a measurement referred to as ***magnitude***.

Ideally, the magnitude of an earthquake would be determined from the amount of material which slides along the fault and the distance is displaced . There is more than one specific definition of magnitude, and more than one scale of magnitude in international use. The ***Richter Magnitude Scale*** is commonly used scale to describe earthquake magnitude consists of nine degrees. The Richter scale is logarithmic, which means that an earthquake of magnitude 4 causes ten times as much ground movement as one of magnitude 3, one hundred times as much as one of magnitude 2, and so on. Magnitudes greater than 8 are rare and special events, and they would usually be perceptible to people more than 600 km away from the epicenter. Earthquakes with magnitudes greater than 5.5 on the Richter Scale are large enough to be recorded on seismographs over the entire earth. While , magnitude of less than 2.5 are usually not felt by humans. The first motion of the ground at such a recording station may be either ***compressional,*** with the first ground motion away from the source, or ***dilational,*** with the first ground motion towards the source. Elastic waves generated by an earthquake can be a mixture of both types.

Intensity of an Earthquake

An alternative way of describing the size of an earthquake by the earthquake's ***intensity*** which measures its destructiveness. ***Earthquake intensity*** is a measure of the earthquake's effect on humans and on surface features. It is not a unique characteristic of an earthquake, nor is it defined on a precise quantitative basis. The surface effects produced by an earthquake of a given magnitude vary considerably as a result of such factors as local geologic conditions, quality of construction, and distance from the epicenter. A single earthquake, then, can produce effects of many different intensities in different places, although it will have only one magnitude assigned to it. Thus, earthquake intensity is a measure of the amplitude of ground vibration ***at one locality***. It is related to the square of the distance of the locality from the epicenter and to the amount of damping of the seismic waves produced by geological conditions along their path to the locality. The most widely applied intensity scale is the ***Modified Mercalli Scale*** which is divided into 12 degrees of intensity. The commonest sources of shallow earthquakes are active faults, and many epicenters are located close to the outcrop of a fault.

For example, the San Francisco earthquake of 1906 was accompanied by visible surface displacement along 430 km of the San Andreas Fault, with a maximum strike-slip displacement of 6.5 m. When faulting occurs, a pattern of compressional (extension) and dilational (contraction) waves are generated, and the pattern can be used to define the movement along the fault plane. A network of seismic stations will determine the changing character of waves associated with an earthquake. From first motion studies a seismologist can determine the orientation of faults and the slip directions of earthquakes anywhere on earth.

5.4.3 Destruction Caused by Seismic Vibration

Nearly all of the structural damage done by an earthquake is a result of the ground shaking associated with the passage of the seismic waves generated by the earthquake. As the energy released by an earthquake travels along the earth's surface, it causes the ground to vibrate in a complex manner by moving up and down as well as from side to side. The amount of structural damage attributable to the vibrations depends on several factors, including:

1- The intensity and duration of the vibrations (earthquakes).
2- The predominant period and frequency of the vibrations.
3- The maximum amplitude and acceleration of motion.
4- The nature of the material upon which the structure rests.
5- The design of the structure.

Thus, structures are affected by both vertical and horizontal components of the ground acceleration. The nature of the ground material on which the structures rest can substantially affect the amplitude of the resulting ground vibrations. Loose, unconsolidated material tend to amplify the wave displacements. If the frequency of the seismic waves is close to the natural oscillation frequency of a building, the amplitude of the building's shaking can be increased by ***resonance***. Finally, it is clear that another important parameter in determining the amount of structural damage is simply the time-duration of the shaking due to the passing waves; this time can vary from only a few seconds to three or four minutes in severe earthquakes.

Designing "earthquake-resistant" buildings is a greater challenge and is a relatively new idea that has developed mainly in the last few decades. Engineers have studied how well different types of building have withstood real earthquakes. Scientists can conduct laboratory experiments on scale models of buildings subjecting them-scale shaking designed to simulate the kinds of ground movement to be expected during an earthquake. It is also important to consider not only how structures are built, but what they are built on. Buildings built on solid rock (bedrock) seem to suffer far less damage than those built on deep soil. Most smaller and older buildings lacked the deep foundations necessary to reach more stable sand layers at depth. Many of these buildings collapsed completely. The duration of an earthquake also affects how well a building survives it. In reinforced concrete, ground shaking leads to the formation of cracks, which then widen and develop further as long as shaking continues. A concrete building that can withstand a one- minute main shock might collapse in an earthquake in which the main shock lasts three minutes.

Thus in-situ seismological recordings include the following:
1- Studying the in-situ seismological activity.
2- Studying the vibrating nature of buildings.
3- Studying the vibrating properties of soil profiles.

5.4.4 Prediction of Earthquakes

Prediction of seismic risk can be assessed from general theory and from past records of an area. It is used for planning and for laying down building codes. Prediction of a specific, destructive earthquake is of greatest value only if it allows evacuation of a threatened city and deployment of emergency services a few days before the event. Prediction approaching this accuracy has been achieved in a few cases since 1973, and the Chinese claim to have successfully evacuated one of their towns in 1975. As elastic strain builds up within rocks close to the focus, over periods as long as decades, minute cracks in the rocks (***microfractures***) open and affect their physical properties. This dilatancy of the rocks increases their volume, and results in minor tilting of the ground surface from the active fault. Subsidence or uplift of the land and changes in movement of a fault zone from a slow creep to a locked position have been found to precede moderate earthquakes. It therefore seems reasonable that earthquakes may be predicted by continually monitoring ground tilt, fault movement, and seismic activity .Some monitoring networks are already operating in the earthquake-prone regions. Small quantities of the ***gas radon*** (generated by radioactive decay of radium), trapped in some rocks, are released and can be detected by analysis of well water. The velocity of seismic waves changes, and V_P / V_S decreases by about 20%. This change can be monitored by local seismic surveys at daily intervals. A day or two before the earthquake, the seismic velocities revert to normal as water seeps into the microfractures. The fluid pressure within the voids of the rock (***pore pressure***) is

increased, and by reducing effective pressures allows movement along the fault to take place. The relationship between pore pressure and earthquakes was first observed when disposal of fluid toxic waste down a deep boring which traversed an active fault accidentally triggered off weak shocks. Control of the potentially destructive San Andreas Fault in California has been proposed by using this triggering mechanism to release as a series of weak, predictable shocks the enormous elastic strain energy that is already stored. Each stage of the programme would require three boreholes, each about 5 km deep and spaced 0.5 km apart along a segment of the fault. Water would be pumped from the outer holes to lock these points on the fault, and would then be injected into the middle hole to reduce friction across the fault plane to give a controlled tremor. This would be repeated along the entire fault. The scheme would cost thousands of millions of dollars for 500 boreholes, plus a less predictable amount in subsequent civil
damages suits. As in many imaginative engineering projects, there are political difficulties as well as economic ones.

5.4.5 Seismic Risk and Problems for the Engineer

An earthquake may be of very small magnitude and only detectable by instruments, but may be powerful enough to cause annoyance or alarm to people and to damage buildings. Seismic risk from ground movements must be foreseen, understood and dealt with in planning and design. Regions of high seismicity are often covered by building laws specified in terms of earthquake parameters, and even in countries of low seismicity, such as Britain, the probability of an earthquake of given power occurring within so many years must be considered in siting potentially dangerous structures like nuclear power generating stations. Information about seismicity and seismic risk is obtainable by referring to the Global Seismology Unit of the BGS in Edinburgh. A catalogue of earthquakes that have been recorded over the previous year is produced by the International Seismological Centre, Newbury, Berkshire. Older catalogues based on questionnaires to the local public and on historical records have been produced by individuals. The historical records have sometimes needed interpretation. For example, the area affected by one earthquake in Scotland at the beginning of the 17th century can be surmised from the records of Aberdeen. The town council decided to enforce a ban on playing golf on the Sabbath shortly after the shock! Seismic activity must be considered when certain engineering structures, particularly dams, are designed. Dams in earthquake zones will be designed with a capacity for resistance to the dynamic forces that can be applied during an earthquake. Before construction begins, past seismological records of the dam site or nearby areas should be checked and major fault lines located. An instrumentation programme should be initiated on the actual site as soon as its location has been determined, particularly with regard to long-term seismic monitoring. The type of ground movements likely to occur should be predicted, and whether any earthquakes that may occur are likely to be of shallow depth, such as by slip along a fault plane, or of deep focus. Structural damage is likely to result from ground displacement, acceleration at low seismic frequencies and velocity from blast vibrations. Ambraseys and Sarma (1967) considered many of these factors in dam design. Earthquakes may cause damage in unconsolidated deposits. Filled ground may consolidate drastically, and studies have been made about the possibility of ***liquefaction*** development, either in the saturated fill material of an earth dam or rockfill dam or in the foundation material. Earth or rockfill dams may fail in several ways during an earthquake. Circular shear failure or rotational failure of the embankment, and planar base failure along the embankment-foundation interface are the three main types. Concrete dams may be subjected to failure by either the second or third of these modes. Other important sources of small local tremors are created by human agency. The impounding of great masses of water in very large reservoirs may result in uneven and spasmodic settlement under the new load. More importantly, the extraction of coal causes collapse of the strata above the seam into the abandoned workings, and often produces small seismic foci. Instead of broad gentle subsidence, slippage may occur locally along a fault, with each jerky movement producing a small shock. Contemporaneously, ***rock bursts*** may explode from any massive rocks in the passageways as they collapse, with each burst acting as the focus of a minor shock. There is disagreement on the details of the mechanism linking seismicity with abandoned workings, and thus about the legal liability for damages associated with them in particular cases, although a genera correlation has been demonstrated in more than one area.

5.4.6 Seismological Studies and Building Designs

The energy is released by an earthquakes through seismic waves causes damage to and sometimes complete failure of buildings, with the surface waves- especially shear surface waves- responsible for most of this damage. Shifts of even a few tens of centimeters can be devastating, especially to structures made of weak materials such as adobe or inadequately reinforced concrete, and as shaking continues, damage may become progressively worse. To avoid such danger, a proper designs of earthquake-resistant structures (buildings, bridges, and dams) must be taken into consideration. The proper designs of such structures such that their frequency must be not equal to that of the usual earthquake occurred in the site of construction. If the frequency of the seismic waves is close to the natural oscillation frequency of a building, the amplitude of the building's shaking can be increased by ***resonance***. The required average frequency indicates that the natural frequency of one-story building is about 5-15 Hz, while for thirty-stories steel frame building is about 1/3 Hz. If the time-duration of the structure is equal to that of the ground, upon which the structure rests, a resonance will occur during an earthquake and structures cracked. But, if the time-duration of the structure, ground and an earthquake are equal, a serious damage is occurred and structures destroyed.

To evaluate earthquake- resistant buildings, the following information must be known:

1- The time-duration of the predominant earthquakes in the area of the structure site.
2- The natural vibration of the ground upon which the structure rests.
3- The natural vibration of the structure.

REVIEW QUESTIONS

5.1 Distinguish among fall, slide, and flow.

5.2 What is controlling force of wasting? What other factors are important?

5.3 Why can rock avalanches move such great speeds?

5.4 What factors lead to the massive rockslides?

5.5 Compare and contrast between mudflow and earthflow.

5.6 Describe the mechanism that leads to the slow downslope movement called creep.

5.7 What is an earthquake? Under what circumstances do earthquakes occur?

5.8 Distinguish between earthquake focus and epicenter.

5.9 List three factors that affect the amount of destruction caused by seismic vibrations.

5.10 Distinguish between the Mercalli scale and Richter scale.

5.11 How might earthquakes be controlled in the future?

5.12 What mechanism does produce a destructive earthquake?

5.13 Show the effects of the following structures on engineering projects:
a- Folds; b- Faults ; c- Joints

5.14 Show the relation between earthquakes and volcanoes.

5.15 What do scientists look for when monitoring a volcano?

5.16 For a dam constructed on a syncline and an anticline rock layers, show the effect for both cases.

5.17 For a tunnel constructed in a syncline and an anticline rock layers, show the effect for both cases.

5.18 Explain the formation of karsts and sinkholes.

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