A **viscous material** is one that is **semi-fluid in nature**. When **stressed**, it will **deform** or tend to deform, any **deformation** being **permanent** because it is not **recovered** when the loading is **removed**.

Elastic materials also **deform** or tend to deform when **stressed**, but, when the **loading is removed**, any deformation is **fully recovered**.

Bitumens are **visco-elastic materials**. The degree to which their behavior is **viscous and elastic** is a **function of both temperature and the period of loading** (usually referred to as the '**loading time**').

At **high temperatures** or **long loading times** they behave as **viscous liquids**, whereas at **very low temperatures** or **short loading times** they **behave as elastic** (**brittle**) **solids**.

The intermediate range of temperature and loading times, more typical of conditions in service, results in **visco-elastic behavior**.

In order to define the **visco-elastic** properties, the **concept of the stiffness modulus** as a **fundamental parameter** to describe the mechanical properties of bitumens by analogy to the **elastic modulus** of **solids** was introduced.

If a tensile stress **s** is applied at a loading time **t = 0**, a strain **ε** is instantly attained that does not increase with the loading time. The elastic modulus **E** of the material is expressed by **Hooke's law** as stress divided by strain.

In the case of **visco-elastic materials** such as **bitumen**, a tensile stress **s** applied at a loading time **t = 0** causes a strain **ε** that **increases**, but not proportionately, with the loading time. The stiffness modulus S_t at a loading time **t** is defined as **the ratio between the applied stress and the resulting strain at the loading time t**.

It follows from the above that the value of the **stiffness modulus** is dependent on the **temperature** and the **loading time** that is due to **the special nature of bitumen**.

Consequently, it is necessary to state both the temperature **T** and the loading time **t** of any stiffness modulus measurement

$$S_{t,T} = \frac{\sigma}{\mathcal{E}_{t,T}}$$

The methods used to measure the stiffness modulus of bitumen are often based on **shear deformations**. The resistance to shear is expressed in terms of the **shear modulus G**, which is defined as

$$G = \frac{Shear\ stress}{Shear\ strain}$$

The elastic modulus and shear modulus are related by **$E = 2(1 + \mu)G$**

where **μ** is **Poisson's ratio**. The value of **μ** depends on the **compressibility** of the material, and may be assumed to be **0.5** for almost incompressible pure bitumens, while values of **<0.5** have to be considered for asphalts.

Thus, **$E \sim 3G$**

Prediction of the stiffness modulus

If direct measurement of the stiffness modulus is **not feasible**, it can be predicted using the Van der Poel nomograph.

Van der Poel showed that two bitumens of the same PI at the same loading time have equal stiffness moduli at temperatures that differ from their respective softening points by the same amount.

Over 40 bitumens were tested with PI values varying from +6.3 to −2.3 at many temperatures and frequencies, using both creep tests and dynamic tests.

From the test data, Van der Poel produced a nomograph from which, using only penetration and the softening point, it is possible to predict the stiffness modulus of a bitumen over a wide range of conditions of temperature and loading times.

Figure 6.17 (Shell Handbook, sixth edition 2015) shows a Van der Poel nomograph with the stiffness modulus determined for a 40/60 pen bitumen at a loading time of 0.02 s and a test temperature of 58°C.

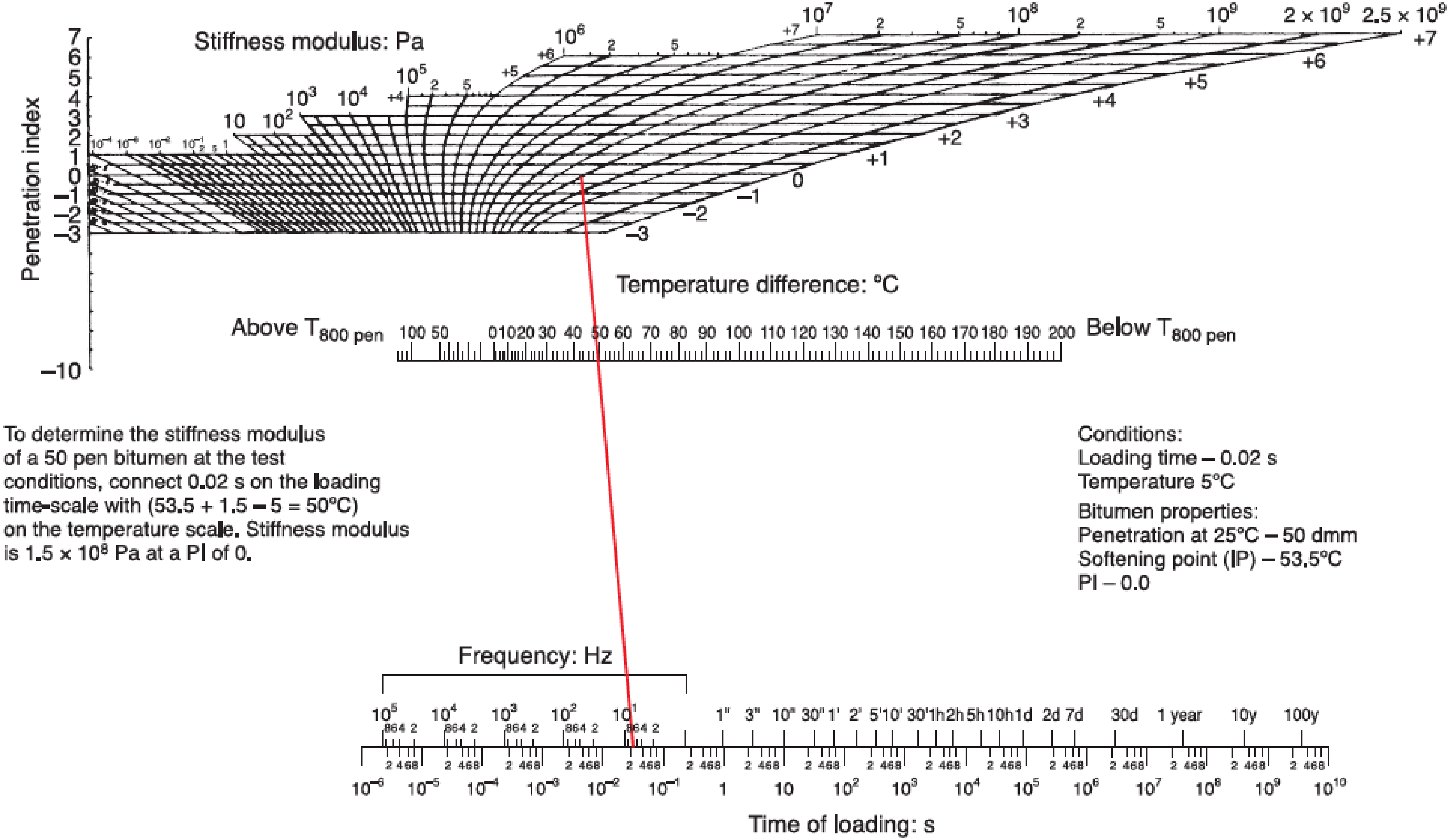

Figure 6.17 Nomograph for determining the stiffness modulus of bitumens

Example/page 19

For a bitumen with **PI= +2** and $\boldsymbol{T_{R\&B}}$=**75°C**. Determine the stiffness modulus $\boldsymbol{S_B}$ of the bitumen at test temperature **-11°C** and frequency of **10 Hz**.

Solution

1) Connect the frequency **10 Hz** represented by Point 1 on the loading time scale with $\boldsymbol{T_{difference}}$ =86°C [75-(-11)] represented by point 2 on the temperature scale.
2) Extend the line to connect the line drawn from **PI= +2** represented by point 3.
3) Mark the resulting intersection point (point 4) on the nomograph.
4) Draw a curve line from the conflict point (point 4) parallel to the main curve lines to intersect the stiffness modulus side (point 5).
5) Predict the stifness modulus from point 5, $\boldsymbol{S_B} = 5 * \mathbf{10^8}\ \mathrm{N}/\boldsymbol{m^2}$.

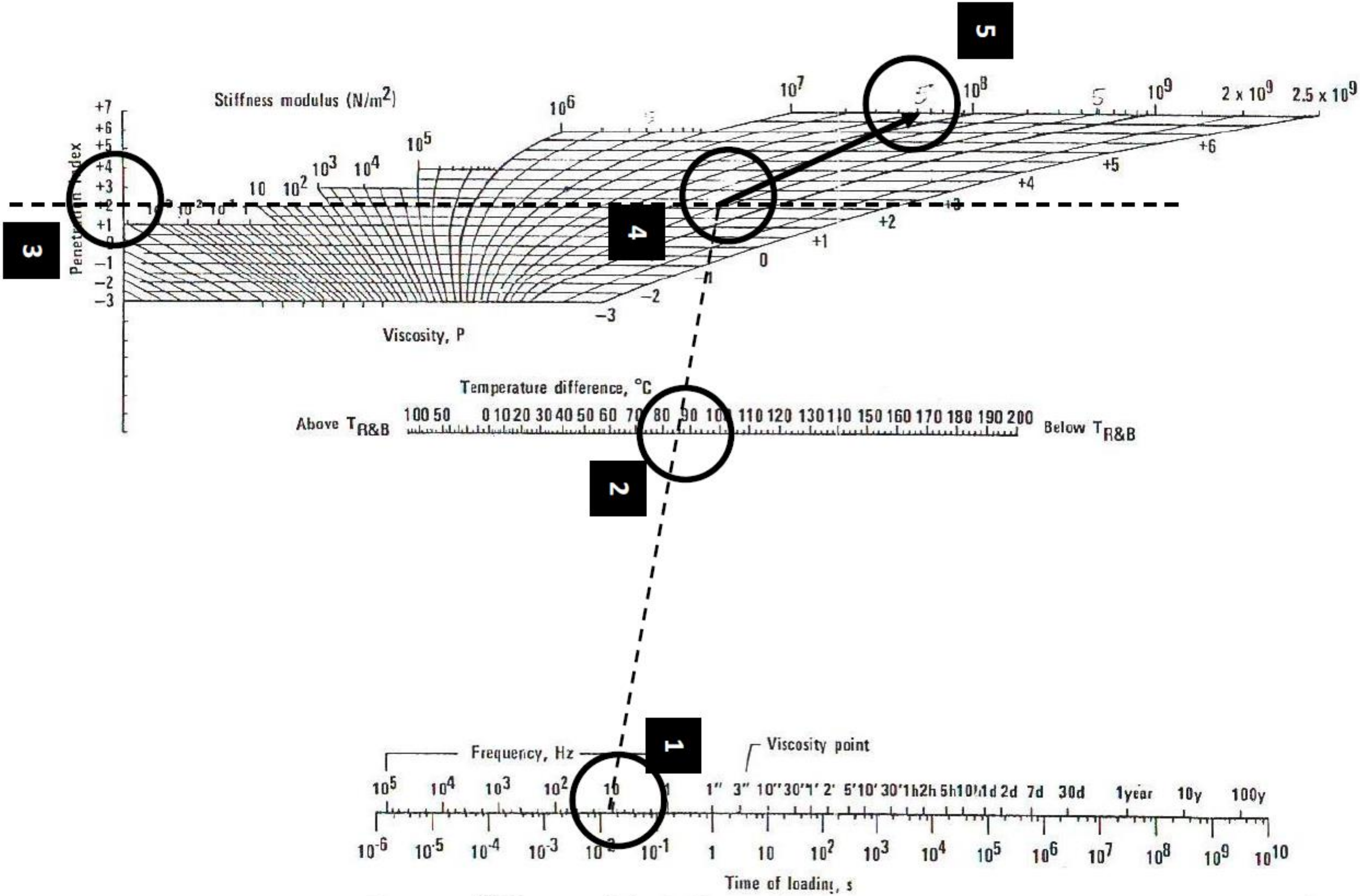

Figure 8.15. KSLA nomograph for S_b (bitumen stiffness). (From Shell Oil Co.)

Frequency (*f*) is the number of occurrences of a repeating event per unit of time.

Frequency is measured in units of hertz (Hz) which is equal to one occurrence of a repeating event per second. Hz = hertz = 1/s.

Frequency means oscillations (cycles) per second.

Ex.

Hz = 1/s = 1/10 = 0.1 Hz

Hz = 1/s = 1/2 = 0.5 Hz

Hz = 1/s = 1/0.5 = 2.0 Hz

Hz = 1/s = 1/1 = 1.0 Hz

التردد يعني التذبذبات (دورات) في الثانية

1 second = 1 s = 1000 ms

1 ms = 0.001 s

1 μs = 0.000001 s

cps = cycles per second