# ESTABLISHMENT OF COVER DEPTH REQUIREMENT FOR UTILITY PIPES IN ARTERIAL ROADS


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Degree of Master of Engineering


Department of Civil Engineering

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Thesis submitted in partial fulfilment of the requirements for the degree

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## DECLARATION

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## ABSTRACT

Pipelines are a safe and economical mean of transporting gas, water, sewage and other fluids. They are usually buried in the ground with substantial protection. Among those utilities, water convey lines would play a vital role in supplying water to the public.

At present, roads have reached their maximum capacity with the increasing of the rapid growth of traffic. Thus, the rehabilitation and widening of roads shall take place to increase the structural integrity of the road pavement and road capacity. At that moment the utility agencies have to decide whether to shift the existing lines (mainly the water lines) or keep them as they are. Therefore, a criterion is needed to decide the minimum distance above the existing lines to cater the new traffic. Furthermore, the cost of removing and replacing utility lines are generally high. Considering these facts, this research intended to identify the safe depths to locate water lines in roads subjected to different traffic loadings.

Existing traffic details of some arterial roads were collected from the Road Development Authority. Heights from the existing road surface to the top of underground pipelines in some of the major roads were collected. The loading calculations were done using the ‘CIRCLY’ software for a selected pavement structure. Then the bending stresses were calculated using equations.

Finally, the safe depth of locating pipes for satisfying the design traffic loading was determined. Furthermore, studies can be carried out on different pavement types with different thicknesses and characteristics of pavement layers.


*Key Words*: Safe depth, CIRCLY, Utility pipes

## DEDICATION

To my Parents and Husband

Who Always Encouraged Me towards Success

**ACKNOWLEDGEMENT**

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I wish to thank Engineer K.H.S.M.Sampath for the guidance given on CIRCLY software. Then special thanks are extended to the staff of Planning Division of RDA for providing the traffic data for my research and Engineer Mrs.V.P.Thirangama, National Water Supply and Drainage Board for giving support in finding related specifications.

Finally, I would like to thank my family and friends for their endless support and encouragement given throughout the period of study.

O.S.Chathurangani
138305G

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## LIST OF ABBREVIATIONS

| Abbreviation | Description |
|---|---|
| DESA | Design Equivalent Standard Axles |
| SADT | Single Axle Dual Tyre |
| PE | Polyethylene |
| PVC | Polyvinyl Chloride |
| DI | Ductile Iron |
| RDA | Road Development Authority |

# 1. INTRODUCTION

## 1.1 Requirement of a proper criterion to find a safe cover depth for Utility pipes

Underground conduits served to improve the living standards of people since the dawn of the civilization. Remnants of such structures from ancient civilizations have been found in Europe, Asia, and even the western hemisphere, where some of the ancient inhabitants of South and Central America had water and sewer systems. These early engineering structures are often referred to as epitomes of the art of engineering. Nevertheless, whether art or science, engineers and scientists still stand amazed at these early water and sewer projects. Today, underground conduits serve in diverse applications such as sewer lines, drain lines, water mains, gas lines, telephone and electrical conduits, culverts, oil lines, coal slurry lines, subway tunnels, and heat distribution lines.

Among them, the water supply lines are buried mainly under the carriageway of major roads. Failure of a critical pipeline is extremely serious and has major consequences in terms of economic loss, social impacts and environmental issues. With the higher growth in traffic and increase in traffic loadings, the existing cover depths of pipes become insufficient. There is a tendency that highway authorities are persuaded to shift the utility lines under the shoulder /foot walk during the rehabilitating or reconstructing of any road. However, the main concern is that the cost incurred due to the shifting of utilities are comparatively high, and it is essential to establish a criteria to decide whether the existing cover depths for those utility lines are adequate or not. Then the highway authorities can decide the exact requirement for shifting. The lines which have enough cover depth can be kept as they are which would be monetarily advantageous to the highway authorities.

This research intends to identify the safe depth of the cover for locating water lines which complies with the design traffic load of each road. Then it would be useful for highway authorities to identify the extent to which the existing pipelines should be removed, and to set a guideline to avoid unnecessarily deep excavations to locate pipes even in low traffic roads.

Currently in Sri Lanka, the Water supply and drainage board uses PVC (poly vinyl chloride), PE (poly ethylene) and DI (ductile iron) Pipes for distribution of water. Among these three types, plastic pipes made of polyethylene (PE) play an outstanding role in water supply. According to A. Frank et.al (2009), typical lifetimes of 50 years are taken for granted for PE pipes which convey the water. According to data obtained from Water board, there are underground pipe lines of more than 50 years of service life. Although the water lines exist for 50 years, the most of the Sri Lankan roads are designed for design life of 20 years.

A typical cross section of a trenching line adopted by the Water Board for laying water lines under the asphalt paved roads, is shown in Figure 1.

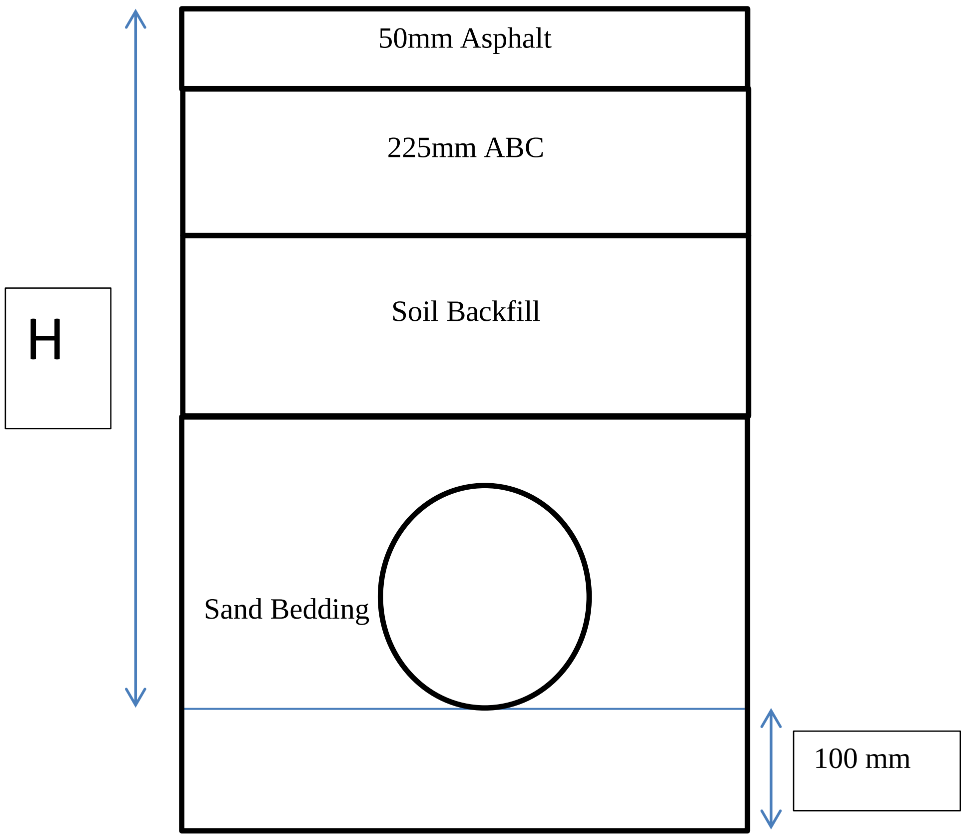


Figure 1 : Cross Section detail of Trench section

The “H” values which are used by the Water Board varies with the pipe diameter, the details are summarized in Table 1,

Table 1: Diameter vs Depth of locating the pipes by Water Board Sri Lanka

| **Detail of Trench for PE pipes** | |
|---|---|
| **Diameter (mm)** | **Depth (m)** |
| 90 | 1.00 |
| 110 | 1.12 |
| 125 | 1.14 |
| 140 | 1.15 |
| 160 | 1.17 |
| 180 | 1.19 |
| 200 | 1.21 |
| 225 | 1.24 |
| 250 | 1.26 |
| 280 | 1.29 |
| 315 | 1.33 |
| 355 | 1.37 |
| 400 | 1.41 |
| 450 | 1.46 |
| 500 | 1.51 |
| 560 | 1.64 |
| 630 | 1.64 |
| **Detail of Trench for PVC pipes** | |
| 63 | 0.9 |
| 90 | 1.1 |
| 110 | 1.2 |
| 160 | 1.2 |
| 225 | 1.3 |
| 280 | 1.3 |
| 315 | 1.35 |

## 1.2 Problem statement

At present most of the roads are widened due to heavily increasing traffic conditions. When road widening is taken place, the underground utility lines which are presently located under shoulders, automatically come under the traffic lanes. Then the impact of moving traffic on those lines becomes higher than they were originally. Therefore, in most occasions the relevant highway authorities request the utility agencies to shift those lines again below the new shoulder or foot walk, which might lead to an increase in cost for relocating purposes. If there is a criteria based on the traffic loading conditions and safe depth of pipes, it may not always necessary to shift lines when the road is widened.

Moreover, the depth of locating pipelines in Sri Lankan roads apparently does not differ with the vehicular traffic, as per the data obtained from utility agencies. It is noted that the same laying depths have been used for the same pipe size and material, irrespective of the traffic conditions in both urban and rural roads, which might be uneconomical for low volume roads as deep underground excavation is extensively costly and has adverse effects on surrounding buildings due to the vibration.

That being the case, developing a criterion to establish a safe buried depth of utility lines for different traffic loadings becomes essential.

### 1.3 Objective

The traffic loading on roads differ from one another, and the present capacities of roads would soon become insufficient with the rapid growth of traffic. The underground utility lines are directly affected by the prevailing traffic condition of each road. Therefore, a criterion has to be made with respect to the traffic load, in order to estimate a safe depth of locating underground pipes. It would be economical and would avoid unnecessarily deep trench excavations. The major objectives of this research are,

- To design safe depths of cover, to locate underground water pipes based on present traffic loads prevailing on road sections.
- To validate the research method by comparing the cover depths obtained from this research with available international standards.

## 2. LITERATURE REVIEW

### 2.1 Failure types of Utility pipes

An underground pipeline failure is a continuous and time-variant process. The failure of pipes can be highly disruptive to both water utilities and to the public users. It has major consequences in terms of economic loss to water utilities, public safety, and damage to property and also has an adverse effect on the overall performance of their assets. There were some researches carried out to find the causes of failure of underground pipes.

(Paradkar, 2012), in his research on "Evaluation of Failure modes for Cast iron and Ductile iron water pipes" had evaluated related studies and found out the modes and causes of failure of pipes. They are summarized in Table 2.

Table 2 : Classification of failure of pipes

| **Type of Failure** | **Modes of Failure** | **Causes of Failure** |
|---|---|---|
| Corrosion and Environment | Pitting Holes | Corrosive soils, microbiological influence. |
| | Graphitization | Corrosive soils, hydrogen embrittlement, stray currents, anaerobic bacteria. |
| | Secondary Effects | Hydrogen embrittlement, chlorides from water, coating damage, ground movements. |
| Stress Failure | Transverse Break | Circumferential stress, thermal stresses, transient conditions, mechanical stresses, soil settlements. |
| | Split Pipe | Ambient temperature differences, transient conditions. |
| Joint Failure | Brittle Failure | Graphitization, coating damage. |
| | Connection Failure | Defects of welding, thermal stresses, fatigue weakening. |
| | Joint Burst | Soil swelling/settlements, differential thermal Expansion/contraction. |

Further he has illustrated the types of failure by using data obtained from a utility agency which is shown in Figure 2. According to that, most failure types are occurred due to the stresses (Transverse break + split pipe) on pipes.

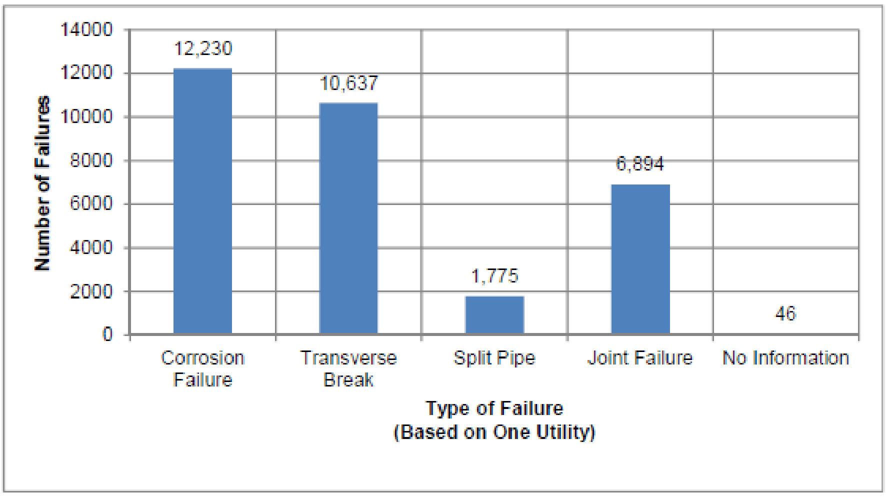


Figure 2 : Types of failures {A.B.Paradkar (2012)}

Ahammed and Melchers (1994) found that the pipe replacement or rehabilitation is typically determined by the performance parameter, i.e. the annual number of failures in a given section of pipe networks.

For buried pipelines subjected to both internal and external loading, a vital failure criterion is the loss of structural strength which is influenced by localized or overall reduction in pipe wall thickness (Ahammed and Melchers, 1997).

"The failure modes of the pipeline differ based on the level of applied external loads, operational conditions and pipe geometry (i.e., diameter and thickness etc). For an example, longitudinal failure occurs due to an increase in internal pressure that increases the tensile stress, surpassing the capacity, while circumferential failure occurs due to the increase in flexural stress in the pipe which exceeds the bending capacity of the pipe. Moreover, "both internal and external pipe corrosion causes leakage and reduces the structural capacity" (J.Kodikara et.al 2014).

Babu et al. (2006) predicted that the underground flexible pipe failure occurs due to deflection, buckling and wall thrust.

A paper published by J.Kodikara et.al (2013) presented common failure modes of pipes and their driving factors which are summarized in Table 3,

Table 3 : Common failure modes of pipes and their driving factors

| **Failure mode** | **Driving factors** |
|---|---|
| Longitudinal split | Internal pressure and corrosion |
| Piece blown out | Internal pressure and corrosion |
| Pin hole | Corrosion |
| Circumferential break | External loadings and ground movement |
| Joint leakage | External/internal loads, thermal loadings and construction defects |

(Cameron, 2005) reviewed some literature regarding design of buried flexible pipes. There, some studies conducted by different researchers have discussed. In his report he has mentioned some uncertainties which the designers have to face with considering the external loadings. They are summarized as follows,

- The amount of load that reaches the pipe in deep embedment
- The amount of load that reaches the pipe due to trafficking of a backfilled surface
- Variations of density that can occur in various zones of pipe installation
- Deformations of the pipe prior to loading due to backfilling process
- The applicability of pipe stiffness tests to pipe installations
- The bond that exists between pipe and surrounding soil

## 2.2 Forces acting on Pipes

Loads are considered as either live (moving) loads or dead (static) loads. Live loads change in position or magnitude; whereas dead loads remain static throughout the design life of the drainage system. The most commonly considered live loads in pipe applications are vehicular loads, usually from trucks, trains or aircrafts. The dead load is the load that comes to the pipe by its surrounding pavement layers. The cover depth for a particular pipe mainly depends on those two types of forces acting on the pipes.

The pipe behavior can be broadly classified as flexible or rigid, depending on its performance once it is installed. Flexible pipes can move, or deflect, under loads without causing any structural damage. Polyethylene, PVC pipes are examples for flexible type pipes. The rigid pipe is sometimes classified as a pipe that cannot deflect significantly without structural distresses, such as cracking. Reinforced and non-reinforced concrete pipes are the examples for rigid pipes.

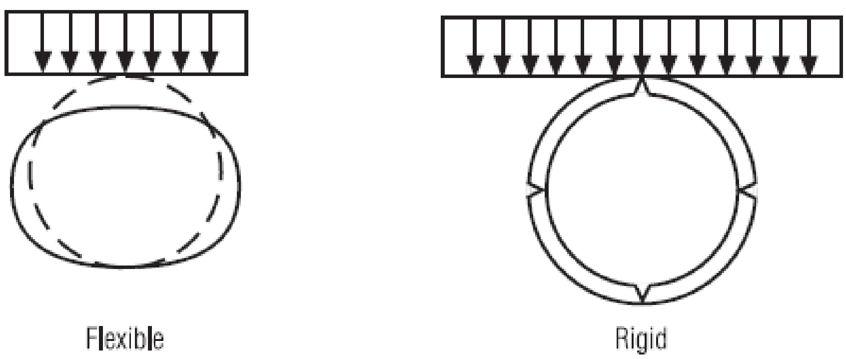


Figure 3 : Response of pipes to loading

American Lifeline Alliance (2001) discussed design provisions of buried steel pipes. The report mainly focused on the loads acting on buried pipes. For the purpose of calculating the vertical earth loads, a steel pipe was considered as flexible. The dead load due to earth was taken as the prism load of soil which has a width equals to the pipe diameter and a height equal to the depth over the pipe.

$$P_v = \gamma C \qquad (1)$$

Where $P_v$ – Earth dead load pressure on pipe

ɣ - Total dry unit weight of fill

C – Height of fill above pipe

Equation no.2 was used in the aforesaid guideline in order to find the live loads which are coming from vehicular traffic,

$$P_p = \frac{3P_s}{2\pi C^2\left[1+\left(\frac{d}{C}\right)^2\right]^{2.5}} \qquad (2)$$

Where $P_p$ - Pressure transmitted to the pipe

$P_s$ – Concentrated load at surface above pipe

C – Depth of soil above pipe

d – Offset distance from pipe to line of application of surface load

There the pressure $P_p$ is increased due to the fluctuating nature of surface loads by multiplying the impact factors mentioned in Table 4.

Table 4: Impact factors

| ***Height of cover , ft*** | ***Installation Surface condition*** | | | |
|---|---|---|---|---|
| | ***Highways*** | ***Railways*** | ***Runways*** | ***Taxiways, aprons*** |
| 0 to 1 | 1.5 | 1.75 | 1.0 | 1.5 |
| 1 to2 | 1.35 | 1.5 | 1.0 | 1.35 |
| 2 to 3 | 1.15 | 1.5 | 1.0 | 1.35 |
| Over 3’ | 1 | 1.35 | 1.0 | 1.15 |

The method of accomplishing live load component has broadly discussed in the report “Design of PE piping systems” (Second Edition Hand Book of PE Pipe, Chapter 6). It has mentioned the pressure transmitted to a pipe by a vehicle depends on the pipe’s depth, the vehicle’s weight, the tire pressure and size, vehicle speed, surface smoothness, the amount and type of paving, the soil, and the distance from the pipe to the point of loading. It discussed the Vehicular loads are based on The American Association of State Highway and Transportation Officials (AASHTO) standard truck loadings. For calculating the soil pressure on flexible pipe, the loading is normally assumed to be an H20 (HS20) truck. A standard H20 truck has a total weight of 40,000 lbs (20 tons). The weight is distributed with 8,000 lbs on the front axle and 32,000 lbs on the rear axle.

Road surfaces are rarely smooth or perfectly even. When vehicles strike bumps in the road, the impact causes an instantaneous increase in wheel loading. Impact load may be found by multiplying the static wheel load by an impact factor. The factor varies with depth. They are summarized in Table 5.

Table 5: Typical Impact Factors for Paved Roads

| Cover Depth, ft | Impact Factor |
|---|---|
| 1 | 1.35 |
| 2 | 1.3 |
| 3 | 1.25 |
| 4 | 1.2 |
| 6 | 1.1 |
| 8 | 1 |

### 2.3 Fatigue damage of Pipes

The traffic loading occurs repetitively and it can be considered as cyclic loading. Fatigue is associated with a large number of repetitive events. Many materials will fail at a lower stress when subjected to repetitive loads than static loads. This type of failure is known as ‘cyclic’ fatigue. The important factors to consider in fatigue are the magnitude of the stress fluctuation, the loading frequency and the intended service life. For smaller pressure fluctuations, a larger number of cycles can be tolerated.

## 2.4 International Standards

Report (Antaki G.A., Adams T.M., 2001) published by the American society of civil engineers presented live loads transferred to the pipes located under trafficked roads, based on the AASHTO HS-20 truck load which are summarized in Table 6.

Table 6: Live load comes from AASHTO HS-20 Truck

| **Height of cover (ft)** | **Live load transferred to pipe** | |
|---|---|---|
| | **lb/ in2** | **MPa** |
| 1 | 12.5 | 0.08618 |
| 2 | 5.56 | 0.03833 |
| 3 | 4.17 | 0.02875 |
| 4 | 2.78 | 0.01916 |
| 5 | 1.74 | 0.011997 |
| 6 | 1.39 | 0.009584 |
| 7 | 1.22 | 0.0084116 |
| 8 | 0.69 | 0.004757 |

The design guide (Second Edition Hand Book of PE Pipe, Chapter 05) has discussed about the live load transferred to PE pipes under road pavements, based on AASHTO HS-25 truck load. Further they summarized the minimum safe depth of covering for trafficked areas based on pipe diameters. The details of their findings are summarized in Table 7 and Table 8.

Table 7: Live load comes from AASHTO HS-25 Truck

| Height of cover (ft) | Live load transferred to pipe (MPa) |
|---|---|
| 1 | 0.108 |
| 2 | 0.048 |
| 3 | 0.036 |
| 4 | 0.024 |
| 5 | 0.015 |
| 6 | 0.012 |
| 7 | 0.011 |
| 8 | 0.006 |
| 10 | Negligible |
| 12 | Negligible |

Table 8: Minimum cover of depth vs pipe diameter

| Inside Diameter of pipe (mm) | Minimum cover (m) |
|---|---|
| 75 | 0.3 |
| 100 | 0.3 |
| 150 | 0.3 |
| 250 | 0.3 |
| 450 | 0.3 |
| 600 | 0.3 |
| 1200 | 0.3 |
| 1350 | 0.5 |
| 1500 | 0.5 |

According to this guideline it is safe to have a cover of 0.3m for pipes having diameter starting from 75mm up to1200 mm.

# 3. METHODOLOGY

## 3.1 Data Collection and Modeling using CIRCLY

The 'CIRCLY 'software was used to find the pressure acting on different depths of the selected pavement. The software required the details of the road pavement above the pipes. Therefore, the following pavement type was proposed to be used with layer thicknesses and material properties. The dead load due to the following pavement composition was also calculated by the software along with the traffic (live) load at each depth level.

Table 9: Road cross section details

| Layer | Thickness (mm) | Young's modulus E) | Poisson 's ratio | CBR | Unit weight(kN/m3) |
|---|---|---|---|---|---|
| Asphalt | 50 | 3000 | 0.3 | _ | 22.55 |
| ABC | 200 | 250 | 0.4 | _ | 21.57 |
| Sub base (soil) | 200 | 150 | 0.4 | _ | 15.91 |
| Sand | 500 | 50 | 0.2 | _ | 14.42 |
| Subgrade | Infinite | _ | _ | 15 | _ |

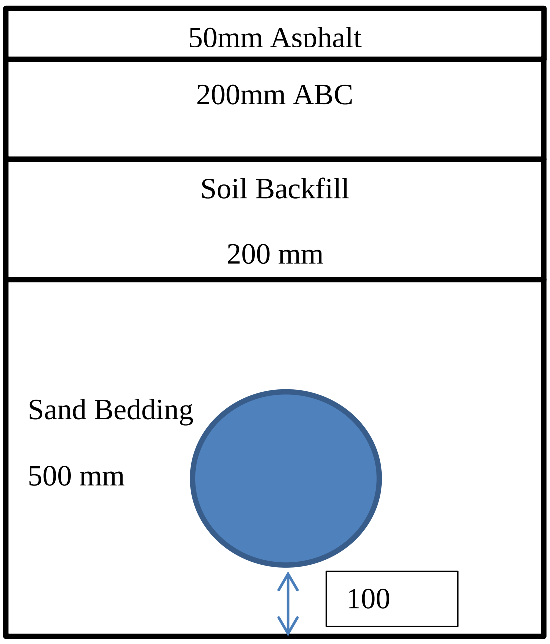


Figure 4: Cross Section detail

CIRCLY software was developed with Austroad guidelines. The Single axle/dual tire (SADT) axle type was defined as the standard axle. In the CIRCLY software, once the Design Equivalent Standard Axle (DESA) load value is calculated for a particular road section, it is applied as SADT movements. The DESA values were based on the traffic data obtained from RDA Planning division.

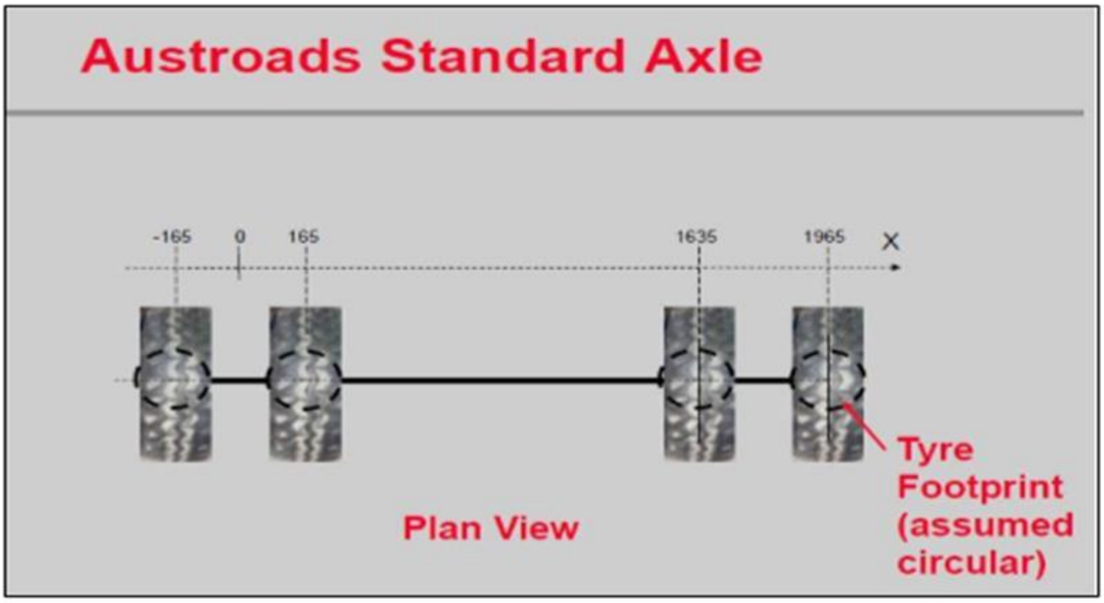


Figure 5: Distance along X axis of standard axle vehicle

The standard axle can be defined in CIRCLY software as in Figure 6.

Load Groups | Load Locations

Equivalent Single Axle (press=0.75 MPa)- Full Axle (Austroads 2004)

| Gear No. | X | Y | Scaling Factor | Theta |
|---|---|---|---|---|
| 1 | -165.00 | 0.00 | 1.00 | 0.00 |
| 1 | 165.00 | 0.00 | 1.00 | 0.00 |
| 1 | 1635.00 | 0.00 | 1.00 | 0.00 |
| 1 | 1965.00 | 0.00 | 1.00 | 0.00 |

Figure 6: Axle configuration detail given to CIRCLY

Once the standard axle is defined, the calculated DESA value can be added as movements. In calculating the DESA values, the design period was considered as 20 years, as most of the Sri Lankan roads are designed for 20 years.

The DESA value input to the software as movements as in Figure 7.

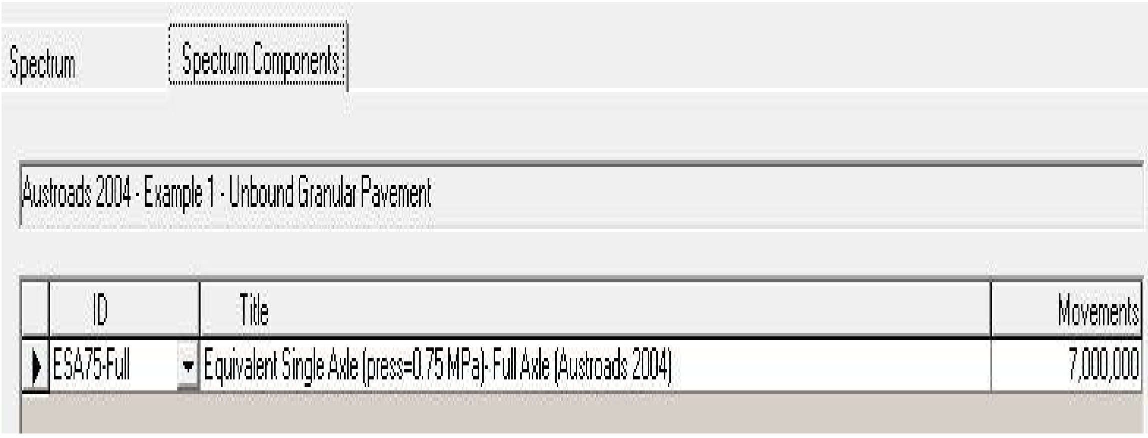


Figure 7: DESA as movements

Then the Z (depth from the top of the pavement) values were given where the pressure values were to be calculated.

## 3.2 Calculation of Bending stresses on pipe and cycles to failure

Once the pressure values were found by ‘CIRCLY’ it was required to find the bending stresses caused by the loadings. There the equations were obtained from a pipe design manual (Chuo,k and Chome 2007).

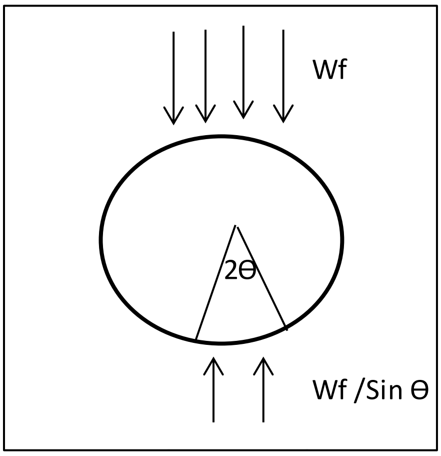


Figure 8: Earth pressure distribution on a buried pipe from backfilled earth

Bending stress on pipe wall due to pavement dead loads was calculated using equation 3 and 4.

At pipe crown,

$$\sigma_{bf} = \frac{6.k_f w_f D^2}{4t^2} \qquad (3)$$

At pipe bottom,

$$\sigma_{bf} = \frac{6.k_f (w_f / sin\theta) D^2}{4t^2} \qquad (4)$$

$w_f$ – Pressure due to pavement dead loads (Specimen calculation is in Annex 01)

$2\theta$ – Supporting angle (assumed 120 degrees so as soft bed condition)

$k_f$ - Coefficient of moment due to dead load - 0.108 (pipe crown), 0.122 (pipe bottom)

D - Pipe diameter (110mm)

t- Net wall thickness (9mm)

Bending stress on pipe wall due to truck loads was calculated using equation 5 and 6.

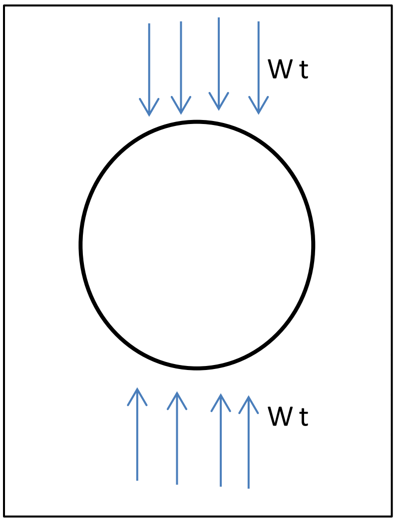


Figure 9: Earth pressure due to truck loads

At pipe crown,

$$\sigma_{bt} = \frac{6.k_t w_t D^2}{4t^2} \qquad (5)$$

At pipe bottom,

$$\sigma_{bt} = \frac{6.k_t w_t D^2}{4t^2} \qquad (6)$$

$k_t$ – Coefficient of moment due to truck load - 0.076 (pipe crown), 0.011 (pipe bottom)

$w_t$ –Earth pressure due to truck load

D - Pipe diameter (110mm)

t- Net wall thickness (9mm)

Here it was essential to separate the dead and live loads, which CIRCLY gives as a combination. Consequently live loads $(w_f)$ acting at different depths for the selected pavement were calculated manually (Annex 01) before calculating bending stresses.

After finding the bending stresses it was required to find the safe depth for each load cycle. There the S_N curve for the material was used to obtain the failure stress for different load cycles. Then the bending stresses calculated previously with the depths were taken along with the failure stresses, to finalize the safe depth for different load cycles.

## 4. RESULTS AND VALIDATION

### 4.1 Results

The pressure due to the combination of dead load and live load acting at different depths of the given pavement type were obtained from the CIRCLY analysis.

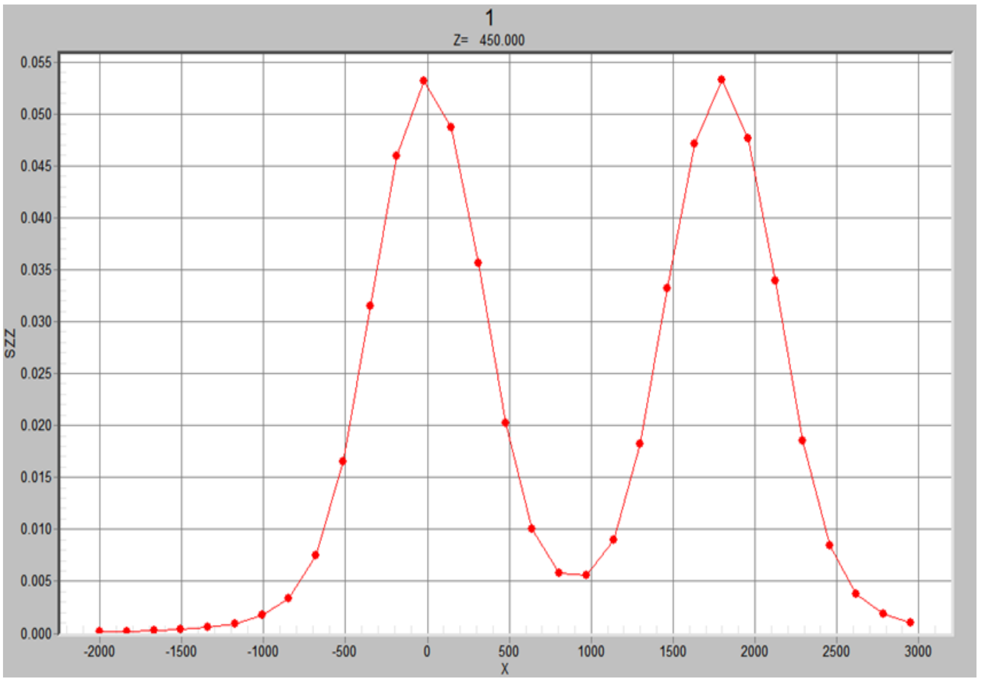


Figure 10: Pressure (MPa) variation at 450mm depth

As per the results, the maximum pressure values were acting below the tire positions of an SADT vehicle. From those, the maximum pressure for each loading was taken for the pipe analysis as a conservative approach. The maximum pressure being just below the wheel path. It cannot be expected that all vehicular traffic follows the same path. Furthermore, the pipe alignment and wheel path of travelling vehicles might not be constant. Taking that into consideration, it is clear that the actual pressure the pipe will have to deal with shall vary (always lesser than the maximum).

The summarized pressure values obtained from ‘CIRCLY’ are summarized in Table 10.

Table 10: Pressure acting at different depths by a SADT vehicle

| **Depth from top of the road surface** | **Pressure acting due to combined (dead and live) loads** |
|---|---|
| 150 | 182 |
| 200 | 131 |
| 250 | 99 |
| 300 | 83 |
| 350 | 70 |
| 400 | 58 |
| 450 | 47 |
| 500 | 42 |
| 550 | 36 |
| 600 | 31 |
| 650 | 27 |
| 700 | 23 |
| 750 | 21 |

The calculation of bending stresses was done using equations as described in the methodology (Annex 01). Then the total bending stress on the pipe at different depths was calculated and they are summarized in Table 11.

Table 11: Total bending stress due to loadings

| Depth [mm] | Total Bending Stress [kN/m2] |
|---|---|
| 150 | 2578.8 |
| 200 | 1812.3 |
| 250 | 1322.6 |
| 300 | 1072.1 |
| 350 | 865.3 |
| 400 | 673.1 |
| 450 | 495.4 |
| 500 | 406.8 |
| 550 | 303.6 |
| 600 | 214.9 |
| 650 | 140.9 |
| 700 | 66.8 |
| 750 | 21.9 |

The stress at failure was calculated using the S_N curve equation.

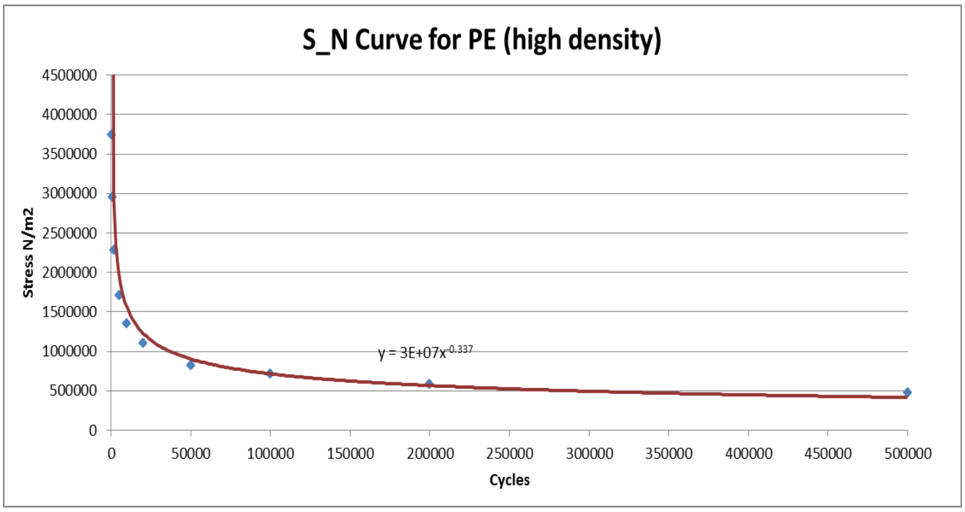


Figure 11: S_N curve for PE material

$$y = 3E + 7x^{-0.337}$$

Where x= cycles to failure y =stress

DESA values, ranging from 3.5E+6 to 15E+6 were taken as cycles of loading, and substituted for the variables in the above equation, to find the stress at failure. The calculated failure stresses for those repetitive load cycles (DESA) are summarized in Table 12.

Table 12: Stress at Failure for Different loading cycles

| **Cycles (DESA for SADT vehicle)** | **Stress at failure kN/m2** |
|---|---|
| 3,500,000.00 | 187 |
| 4,500,000.00 | 172 |
| 5,500,000.00 | 161 |
| 6,500,000.00 | 152 |
| 7,500,000.00 | 145 |
| 8,500,000.00 | 139 |
| 9,500,000.00 | 134 |
| 10,000,000.00 | 131 |
| 12,000,000.00 | 123 |
| 15,000,000.00 | 114 |

Table 11 which specifies stresses at different depths, and Table 12 which specifies stresses at the failure for different cycles, were used to find the safe depth for locating pipes. At a certain depth, if the stress acting due to loading (Table 11) was less than the stress at failure (Table 12) for a certain DESA, then that depth was taken as a safe depth for that particular DESA value. The safe cover for different traffic was obtained using the above criteria and was summarized in Table 13.

Table 13 Safe cover depth for different traffic loadings

| **Traffic Cycles (DESA)** | **Safe Depth [mm]** |
|---|---|
| 3,500,000.00 | 650 |
| 4,500,000.00 | 650 |
| 5,500,000.00 | 650 |
| 6,500,000.00 | 650 |
| 7,500,000.00 | 650 |
| 8,500,000.00 | 700 |
| 9,500,000.00 | 700 |
| 10,000,000.00 | 700 |
| 12,000,000.00 | 700 |
| 15,000,000.00 | 700 |

## 4.2 Validation of the findings

The results obtained from this research can be compared with the data presented in previous studies, for validation purposes. The stresses at certain depths due to the SADT vehicle load (Annex 01) were compared with other similar studies presented in Table 6 and Table 7.

Table 14: Comparison of Results with similar studies

| Height of Cover (ft) | Live load transferred to pipe (MPa) | | |
|---|---|---|---|
| | AASHTO HS 20 Truck | AASHTO HS 25 Truck | SADT vehicle |
| 1 | 0.086 | 0.108 | 0.076 |
| 2 | 0.038 | 0.048 | 0.020 |

There were two studies based on AASHTO traffic loadings as given in the above table. This research was conducted based on SADT loading. The loadings acting are not equal for the three vehicles with different axle configurations (Annex 01). Comparing the axle loadings, the higher value is given by the HS-25 truck. The SADT vehicle showed the lowest stress level. Considering that, results obtained for the SADT vehicle can be treated as acceptable.

According to the findings of this research, the safe cover for the 110mm diameter pipes, for DESA values ranging from 3.5 x 10^6 to 15 x 10^6, ranged from 650mm to 700 mm. In actual practice (as indicated in the following figures) the thickness of asphalt and ABC layers are almost greater than 300mm. Laying of pipes inside Asphalt or ABC is impractical (figure a and b) as it would damage the pipes during the laying operation and will also not provide a smooth and uniform surrounding for the pipe. Further there should be a sufficient height from the bottom of the ABC layer to the top of the pipe, because if not, damage could occur during construction (vibrations).

Considering those facts, the most suited cover for pipes can be considered as one greater than 400 mm (Figure c) making 650 mm a much safer installation.

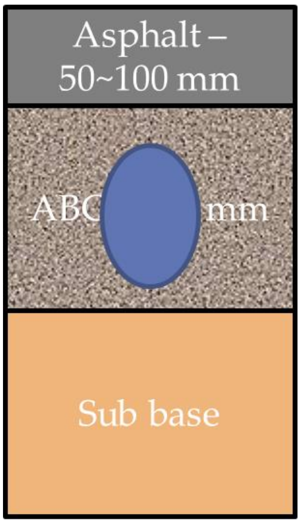


Figure a

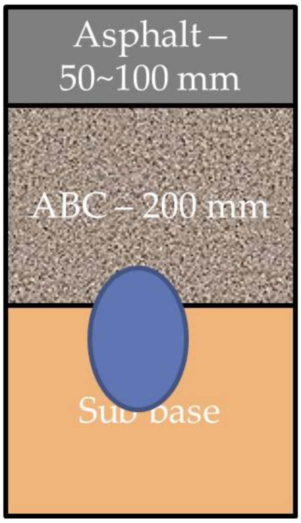


Figure b

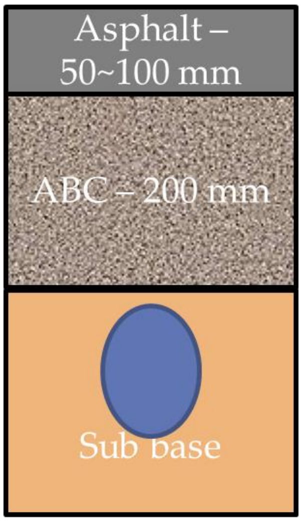


Figure c

# 5. CONCLUSIONS AND SUGGESTIONS FOR FUTURE WORK

This research studied the behavior of buried pipelines subjected to external traffic and pavement loading. Data tables were developed to enable the selection of safe depths for locating pipes in roads with different traffic loading conditions. In developing these charts, the CIRCLY software and equations were used. Some details of existing water line depths were obtained from relevant authorities. The mostly used type of pipe was the PE pipe with a 110 mm diameter. Therefore, this research was done based on that diameter with a selected cross section of a road.

As per the results, the safe cover varies from 650 mm to 700 mm. Considering the practical installation, it is obvious a depth greater than 400 mm is required as a safe cover.

Taking all the aforementioned facts into consideration, the following proposals are suggested for future studies,

- This research was conducted for one selected pavement type. However, different road pavement types in use can be analyzed.

- The research analyzed only 110mm diameter PE pipes. To take it a step further, different pipe diameters can be studied, and the area of research can be further extended to PVC and DI pipes which the water board uses to supply water.

- As per the information received from the Water Board, some of the already laid pipelines have been aging for more than 40 years. Even though most of the roads are designed for 20 years, water lines can last for more than 40 years. As per the Table.1, the minimum cover that the Water board is adopting in laying pipes under asphalted roads is 1 m. This higher cover depth might be the reason for the long lasting nature of underground pipelines. Accordingly, the research area of this study can be broadened to discover safe depths to attain 30, 40 years of design traffic.

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**Annex 01**

Pressure acting due to dead load and live load at different depths

Due to dead loading

| Depth [mm] | Wf [kN/m2] |
|---|---|
| 150 | 3.28 |
| 200 | 4.36 |
| 250 | 5.44 |
| 300 | 6.24 |
| 350 | 7.03 |
| 400 | 7.83 |
| 450 | 8.62 |
| 500 | 9.34 |
| 550 | 10.07 |
| 600 | 10.79 |
| 650 | 11.51 |
| 700 | 12.23 |
| 750 | 12.95 |

Due to live loading

| Depth [mm] | Wt [kN/m2] |
|---|---|
| 150 | 178.72 |
| 200 | 126.64 |
| 250 | 93.56 |
| 300 | 76.76 |
| 350 | 62.97 |
| 400 | 50.17 |
| 450 | 38.38 |
| 500 | 32.66 |
| 550 | 25.93 |
| 600 | 20.21 |
| 650 | 15.49 |
| 700 | 10.77 |
| 750 | 8.05 |

Bending stress at pipe crown due to dead loads

| Depth [mm] | B.Stress [kN/m2] |
|---|---|
| 150 | 79.5 |
| 200 | 105.6 |
| 250 | 131.7 |
| 300 | 150.9 |
| 350 | 170.2 |
| 400 | 189.4 |
| 450 | 208.7 |
| 500 | 226.1 |
| 550 | 243.6 |
| 600 | 261.0 |
| 650 | 278.5 |
| 700 | 295.9 |
| 750 | 313.4 |

Bending stress at pipe crown due to live loads

| Depth [mm] | B.Stress [kN/m2] |
|---|---|
| 150 | 3043.5 |
| 200 | 2156.6 |
| 250 | 1593.3 |
| 300 | 1307.2 |
| 350 | 1072.3 |
| 400 | 854.4 |
| 450 | 653.5 |
| 500 | 556.1 |
| 550 | 441.7 |
| 600 | 344.2 |
| 650 | 263.8 |
| 700 | 183.4 |
| 750 | 137.1 |

Bending stress at pipe bottom due to dead loads

| Depth [mm] | B.Stress [kN/m2] |
|---|---|
| 150 | 103.7 |
| 200 | 137.7 |
| 250 | 171.8 |
| 300 | 196.9 |
| 350 | 222.0 |
| 400 | 247.1 |
| 450 | 272.2 |
| 500 | 295.0 |
| 550 | 317.7 |
| 600 | 340.5 |
| 650 | 363.3 |
| 700 | 386.0 |
| 750 | 408.8 |
| 800 | 431.5 |
| 850 | 454.3 |
| 900 | 477.1 |
| 950 | 499.8 |

Bending stress at pipe bottom due to live loads

| Depth [mm] | B.Stress [kN/m2] |
|---|---|
| 150 | 440.5 |
| 200 | 312.1 |
| 250 | 230.6 |
| 300 | 189.2 |
| 350 | 155.2 |
| 400 | 123.7 |
| 450 | 94.6 |
| 500 | 80.5 |
| 550 | 63.9 |
| 600 | 49.8 |
| 650 | 38.2 |
| 700 | 26.5 |
| 750 | 19.8 |

HS 20 Truck

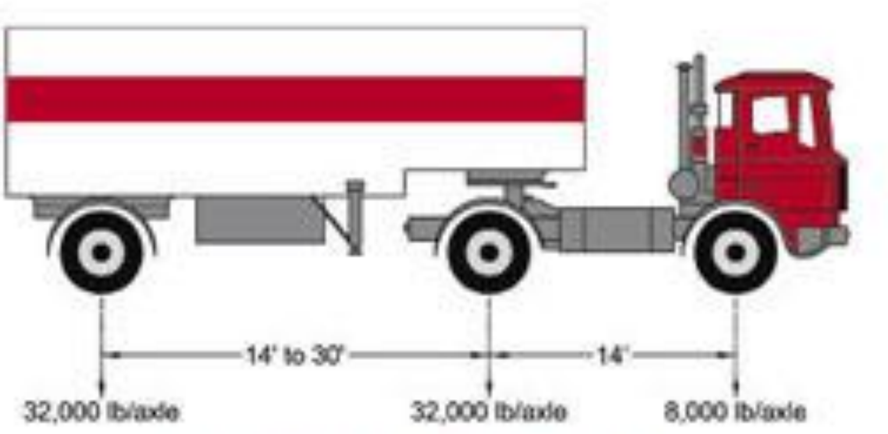
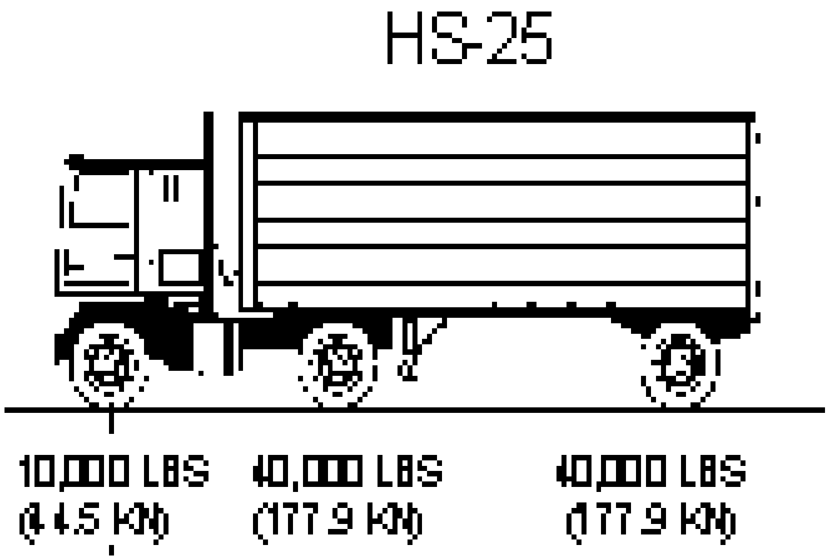
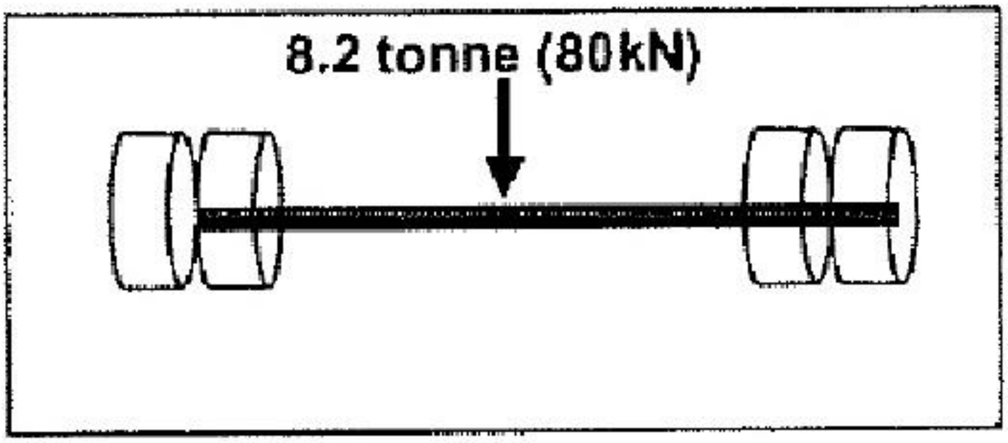



FIGURE 2: HS20 TRUCK

HS 25 Truck



SADT configuration




**Specimen calculation for obtaining the live load acting on the pipe in Table 11**

CIRCLY software gives the combined pressure which comes due to dead load and live load. To find live load, it is required to separately calculate dead load component. For obtaining dead load for the pipe 2 ft below the selected pavement,

P=ɣC ɣ-unit weight (kN/m3) , C- depth of each layer above pipe top level

| **Layer** | **Unit weight (kN/m3)** | **Depth (m)** |
|---|---|---|
| Asphalt | 22.55 | 0.05 |
| ABC | 21.57 | 0.2 |
| Soil | 15.91 | 0.2 |
| sand | 14.42 | 0.15 |

P= (22.55x0.05)+(21.57x0.2)+(15.91x0.2)+(14.42x0.15)

= 10.79 kN/m2

Dead + live load acting at 2 ft depth (Table 7) = 31 kN/m2

Live load ($w_f$) = 31 – 10.79

= 20.21 kN/m2

= 0.020 MPa