ANDRZEJ KULICZKOWSKI[1],
EMILIA KULICZKOWSKA[2],
ANNA PARKA[3]

Kielce University of Technology
al. Tysiąclecia Państwa Polskiego 7
25-314 Kielce, Poland
[1] e-mail: akulicz@tu.kielce.pl
[2] e-mail: emkulicz@tu.kielce.pl
[3] e-mail: ania.parka@interia.pl

THE LOADINGS DUE TO TRAFFIC CONSIDERED IN DESIGN OF TRENCHLESS REHABILITATION OF SEWAGE PIPES

Abstract

New method "KA-17" used for making calculations of the values of road traffic loads and created by prof. Andrzej Kuliczkowski, is presented here. Proposed method considers the influence of different types of soil placed above existing sewers on the values of road traffic loads acting on sewers. Several curves created for different diameters, different types of soil and vehicles and expressed as a function of a height of soil column above the sewer are also given. Attached examples explain how the values of road traffic loads change depending on the above mentioned parameters. Besides a comparative analysis of two methods used for making calculations of the values of road traffic loads (according to Scandinavian and KA-17 methodology) is included in the paper.

Thorough analysis of basic problems that the one can face during determining the values of a dynamic coefficient is also presented. Additionally the influence of a reducing coefficient expressed among the other things. As a function of different types of a road surface on final values of loadings acting on sewer is explained.

Following the results of thorough researches above mentioned analyses are recommended as an especially useful for e.g. evaluation of a safety coefficient of sewer to be renovated or for calculations of optimum wall thickness of linings used for trenchless reconstruction of sewers as well as other pipes used for underground constructions.

Keywords: trenchless technology, underground constructions, pipe rehabilitation

1. Introduction

The selection of suitable road traffic load values is important in case of pipes laid very shallow under the surface. It's well known that an increase in the depth of sewers causes a significant decrease in traffic loads. Establishing the correct traffic load values is also important for determining the values of a safety coefficient of existing sewage pipes. If the values of these coefficients are not satisfactory, it's recommended to conduct trenchless rehabilitation of existing sewage pipes. That would guarantee their constructional safety.

In case of trenchless rehabilitation of underground pipes, including reconstruction and replacement of pipes, it is required to design a lining substituting for a host pipe. It has significant impact on the wall thickness of these linings and consequently on the total budget of such rehabilitation.

The most essential problems connected with making calculations of the above mentioned loadings will be discussed below. Besides the new original method destined for calculating the values of these loadings (with a consideration for the type of soil above the pipe) will be presented.

2. The new method for calculating the values of road traffic loads

To sum up the road traffic loads acting on a sewer laid in the ground it is allowable to apply an approximation assuming both a $\Pi/4$ (45°) angle, at which the loadings are transmitted deep into the ground and an even distribution of vertical stresses. Some of the authors recommend to assume lower values of the above distribution angle equaled for example $\frac{2}{9}\Pi$ (40°) or $\frac{7}{36}\Pi$ (35°).

The other way of calculating the road traffic load values is to use the formulas based on the theory of elasticity, including Boussinesg's formula (Eq. 1)

$$p_{vz} = \frac{3 \cdot W_{1(2)} \cdot h^3}{2 \cdot \pi \cdot \left(h^2 + x_k{}^2\right)^{\frac{5}{2}}} \quad (1)$$

All parameters included in the above formula are explained in Figure 1.

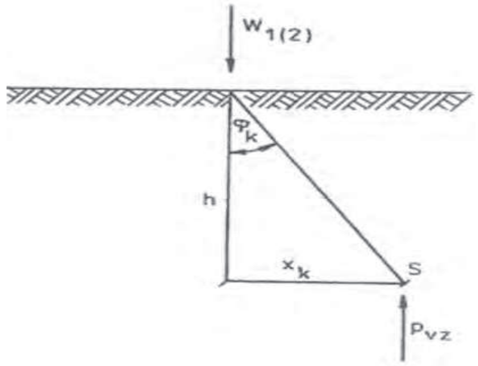

Fig. 1. A half space loaded with concentrated force

The Boussinesg's formula does not take into consideration the influence of different types of soil on final road traffic load values, thus a load curves were created. These curves were derived from equation 2 assuming the values of coefficient k_u taken from the graph presented in Figure 2.

$$p_{vz} = k_u \cdot \frac{W_{1(2)}}{h^2} \quad (2)$$

While making calculations according to the equation number 2 one considers the type of soil above the sewer and the location of the force specified as *W* in reference to the sewer axis. For the considered point *A* (Fig. 1) the loadings due to all concentrated forces acting on the surface should be calculated and summed up.

The method of calculating the values of loadings due to ground was described in [3-5]. The above methodology, known as KA-17, is original presents the correlation between the road traffic load values and the depth of sewer, sewer diameter and the type of soil surrounding the sewer.

The authors created the load curves for different vehicles' weight i.e. 100 kN, 150 kN, 300 kN. The separate curve was done for a wheeled tractor weighting 800 kN since it generates so called special loadings. The curves are applicable to sewers of 0.1; 0.5; 1.0; 1.5; 2.0; 3.0 m in diameter laid in one of the following types of the soil: both non-cohesive and non-compacted soil, non-cohesive but compacted soil, lowly cohesive soil, ground of average cohesiveness or highly cohesive soil provided the cover depth of sewer is between 0.5 m and 8.0 m. The curves are presented in Figures 3-7.

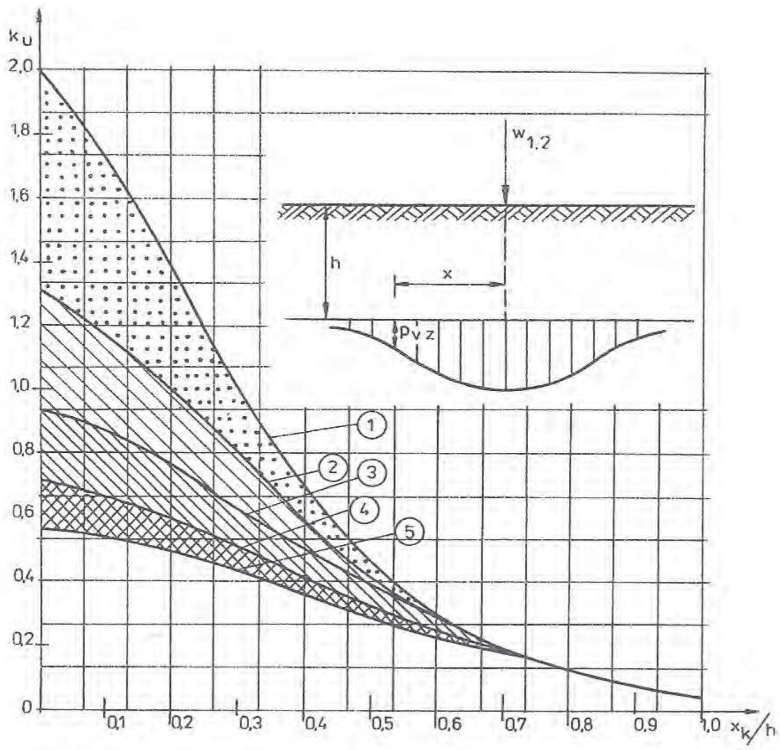

Fig. 2. The values of coefficient k_u for different types of soil [4]: 1 – non-compacted soil; 2 – non-cohesive but compacted soil; 3 – lowly – cohesive soil; 4 – ground of average cohesiveness; 5 – highly cohesive soil

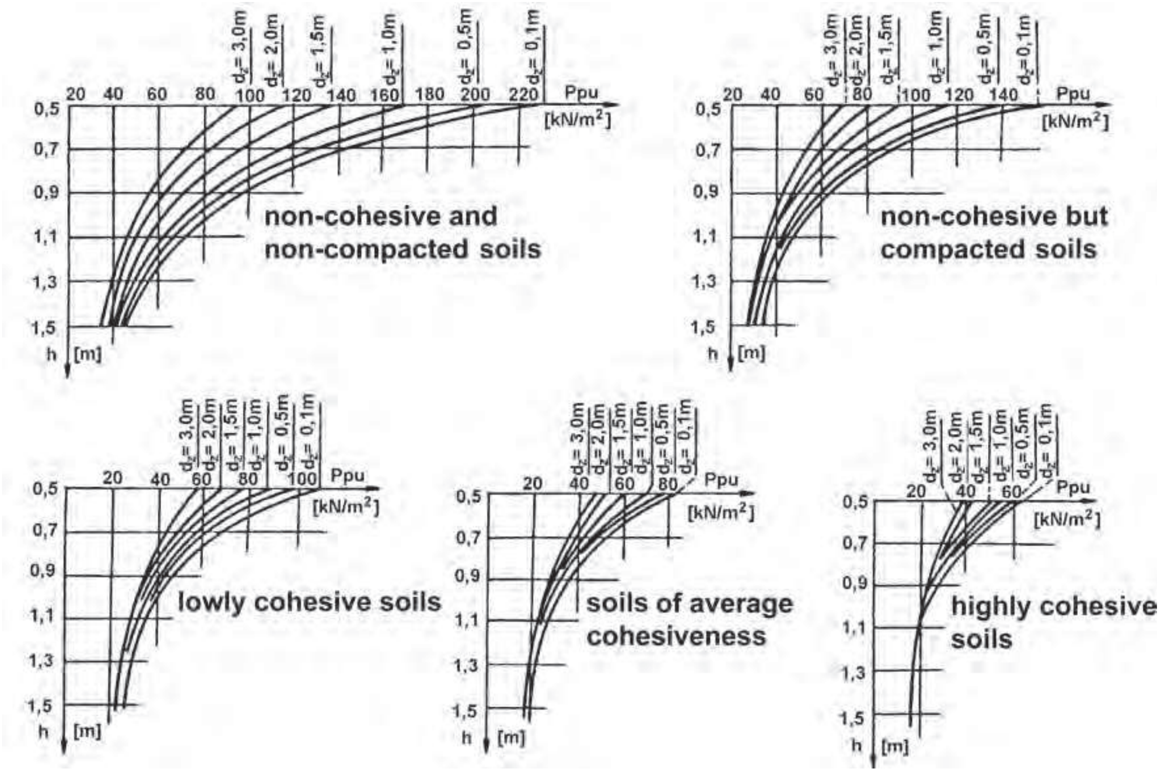

Fig. 3. The loadings due to vehicle of 300 kN for a cover depth *h* between 0.5 m and 1.5 m; for a sewer diameter between 0.1 m and 3.0 m and for 5 different types of soil.

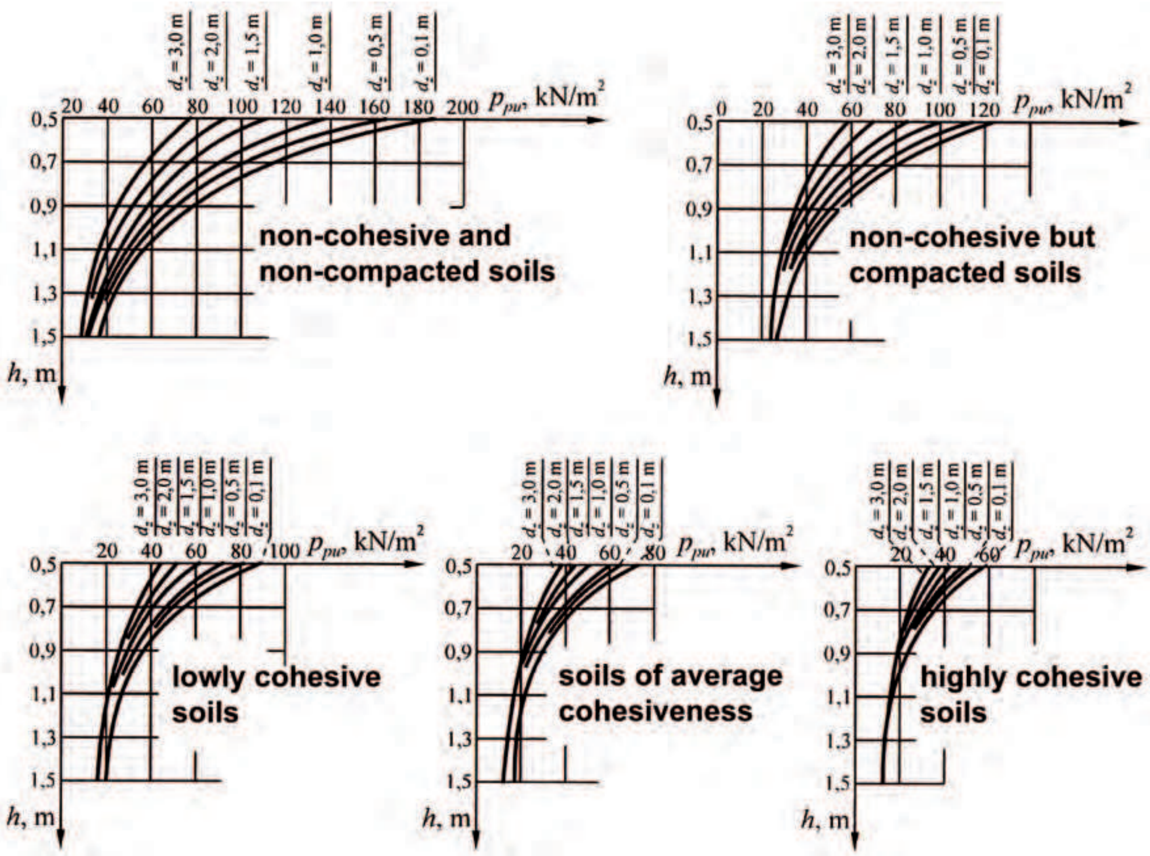

Fig. 4. The loadings due to vehicle of 150 kN for a cover depth *h* between 0.5 m and 1.5 m; for a sewer diameter between 0.1 m and 3.0 m and for 5 different types of soil.

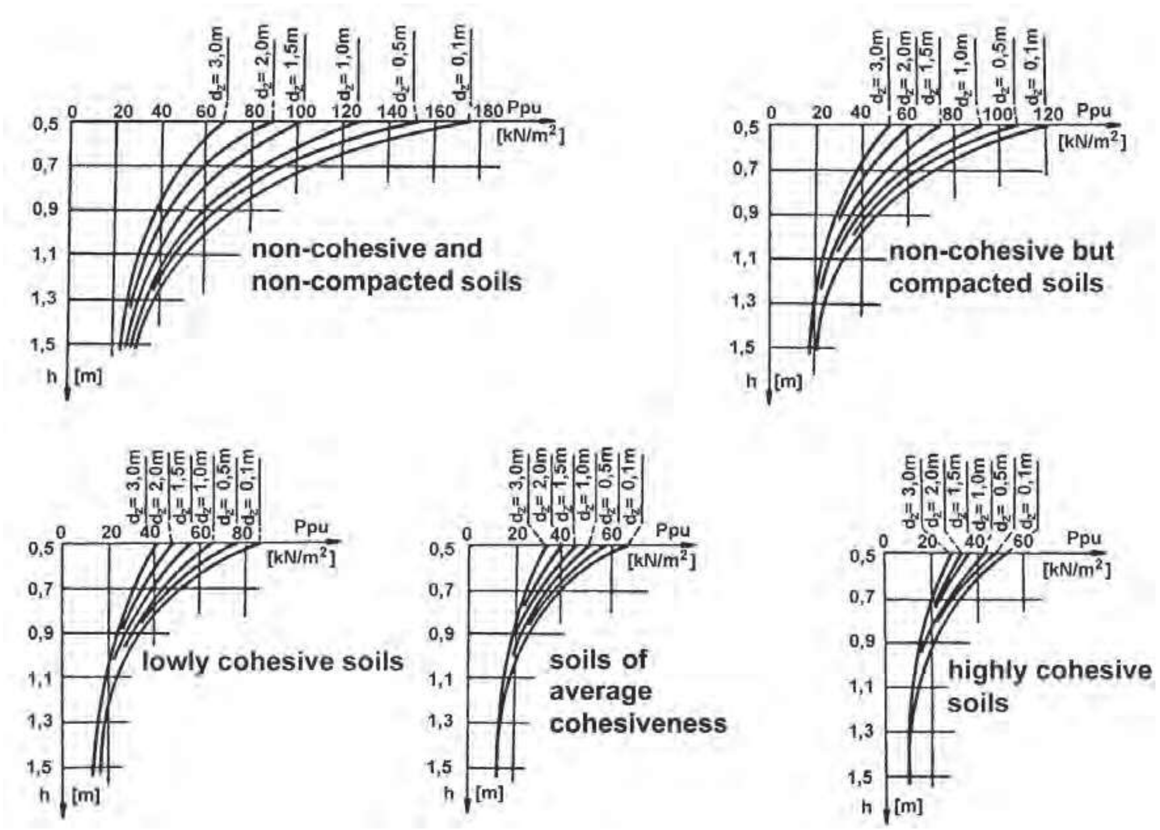

Fig. 5. The loadings due to vehicle of 100 kN for a cover depth *h* between 0.5 m and 1.5 m; for a sewer diameter between 0.1 m and 3.0 m and for 5 different types of soil.

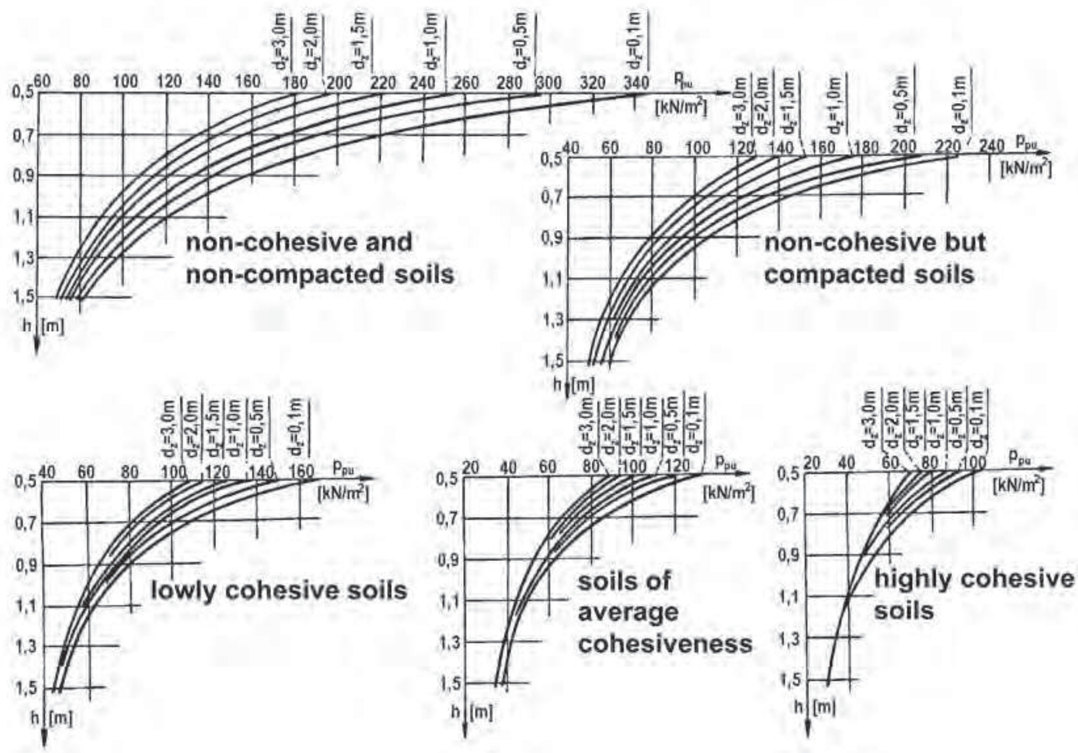

Fig. 6. The loadings due to wheeled tractor of 800 kN (special loading) for a cover depth *h* between 0.5 m and 1.5 m; for a sewer diameter between 0.1 m and 3.0 m and for 5 different types of soil

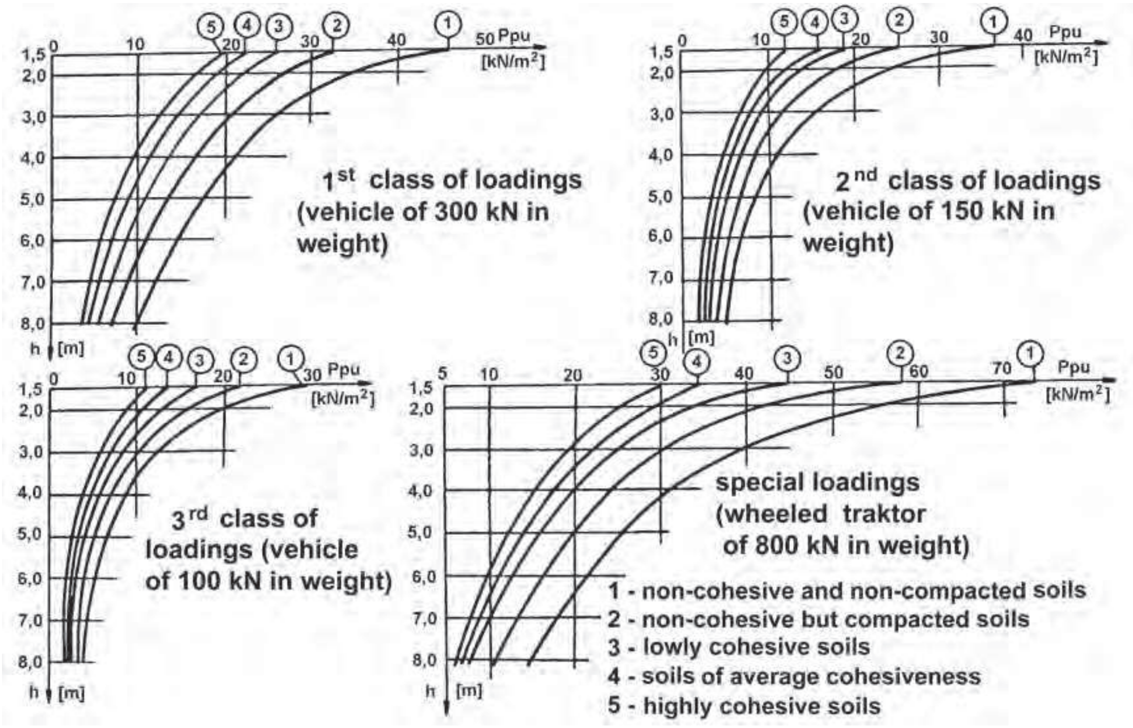

Fig. 7. The loadings due to vehicles of 300 kN, 150 kN and 100 kN and due to wheeled tractor for a cover depth *h* between 1.5 m and 8.0 m; for 5 different types of soil

In case of sewers under roads of heavy traffic it's recommended to consider higher out of two values of loadings calculated both for the wheel tractor K-800 (without dynamic coefficient) and for the vehicle of 300 kN in weight. The sewers under roads of light traffic are recommended to be designed on the basis of loadings generated by the vehicle of 150 kN, while the sewers beyond the road zones – by the vehicle of 100 kN.

The graphs of numbers between 3 and 7 indicate how important role the type of soil could play. So, in the case of highly cohesive soil, for the vehicle of 300 kN and assumed depth of 1.1 m (above the sewer crown) the maximum load equaled to 20 kN/m^2. However for non-cohesive and non-compacted soils, the maximum load equaled to 72 kN/m^2, which is 3 times higher than the previous one. The highest discrepancies exist {occure, take place} in case of the vehicle of 800 kN. Assuming, that the cover depth remains still at 1.1 m, these values are respectively: 20 kN/m^2 for highly cohesive soil; and the maximum value of 120 kN/m^2 for both: non-cohesive and non-compacted soil. That is about 6 times higher, then for the vehicle of 300 kN and the maximum load of 20 kN/m^2. These discrepancies decrease with the depth. For example, for an assumed depth of 5.0 m and the vehicle of 300 kN, the values of these loadings are: 7 kN/m^2 in case of highly cohesive soil and 17 kN/m^2 in case of non-cohesive and non-compacted soil – which is about 2.5 times higher.

3. A dynamic coefficient for traffic loads

Establishing the values of a dynamic coefficient (necessary for further calculations) is more complex. Following the Polish standards it's recommended to calculate the value of a dynamic coefficient using the formula:

$$f_d = 1 + \frac{1 - h}{1 + 0.15 \cdot d_z} \qquad (3)$$

where: h – the cover depth of sewer and d_z – exterior diameter of a pipe.

The equation 3 is applicable to sewers for which the depth is between $0.5 < h < 1.0$ m. If $h > 1.0$ m one should assume f_d equals 1.0. The recommendations introduced to these standards differ from those given by foreign standards. What's more, most of these recommendations are inconsistent with the physical lows there is no information available about the function describing the tendency for its because they are based on the wrong assumption that dynamic impacts fade at the depth of 1.0 m below the ground level.

Following the Swiss standards SIA 190, it's recommended to assume a constant value of the dynamic coefficient f_d = 1.3 independent from the depth of sewer. In German standards ATV-DVWK-A 127P the value of a dynamic coefficient is determined according to Table 1 for each assumed depth of sewer. According to Scandinavian method a dynamic coefficient changes from 1.75 to 1.0 for a depth of 0.5 m to 6.0 m, respectively.

Table 1. The values of a dynamic coefficient according to standards ATV-DVWK-A 127P.

The type of vehicle	f_d
Heavy vehicles	1.2
Normal vehicles	1.4
Light vehicles	1.5

The in-situ tests conducted in France enabled to determine the correlation between the values of a dynamic coefficient f_d and the smoothness of a road surface, travelling speed of vehicles and their weight. These tests confirmed independence of a dynamic coefficient from the depth of sewer. They revealed its constant values and the fact, that it could be higher than the ones suggested by SIA 190 or ATV-DVWK-A 127P. Considering even the least advantageous case of the speed of vehicle, it's weight and irregularity of a road surface , the value of a dynamic coefficient reaches value of 2.0. Based on the equation 4 and the graphs created as a result of in-situ tests it is possible to calculate the value of a dynamic coefficient (provided a designer has detailed information on maximum values of irregularity of a road surface):

$$f_d = 1.1 + 20 \cdot h_n \qquad (4)$$

where h_n is maximum irregularity of a road surface [m]

For example for h_n = 0.01 m one gets f_d = 1.3; for h_n = 0.02 m f_d = 1.5 while for h_n = 0.045 m one gets f_d = 2.0. The in-situ test conducted in France confirmed the Swiss recommendations on assumption of f_d = 1.3 if the maximum value of irregularity of a road surface does not exceed 10 mm.

4. A reducing coefficient for traffic loads

If the road traffic loads are transmitted to a sewer by a road surface it is required to multiply them by a reducing coefficient f_n. It's necessary to consider than the influence of a road stiffness on a load relief to a sewer laid under the surface. The coefficient f_n depends on strain modulus of the soil, modulus of elasticity of a road surface and a factor expressed as a function of length and width of a load area as well as the thickness of a road surface. The modulus of elasticity of a road surface E_n and the strain modulus of the soil E_m are taken from the tables included in [4, 5]. The modulus of elasticity E_n varies between 50 and 150 MPa depending on the type of the surface. The strain modulus of the soil E_m is assumed for the compaction factor of the soil I_s = 100% and it varies between 10 and 40 MPa depending on the type of soil. The values of t_u and a_s can be calculated using the equations (5) and (6).

$$t_u = \frac{E_n}{E_m} \quad \text{and} \quad a_s = \sqrt{\frac{s_p \cdot d_p}{\pi}} \qquad (5) \text{ and } (6)$$

where:

s_p, d_p – the width and length of contact surface between the wheel and the road surface; they are given in [4, 5], for example for the vehicle of 300 kN s_p = 0.6 m and d_p = 0.2 m

a_s – the radius of the so-called load area equivalent surface [mm],

g_n – the thickness of the pavement [mm].

The values of f_n can be taken from the curve presented in Figure 8.

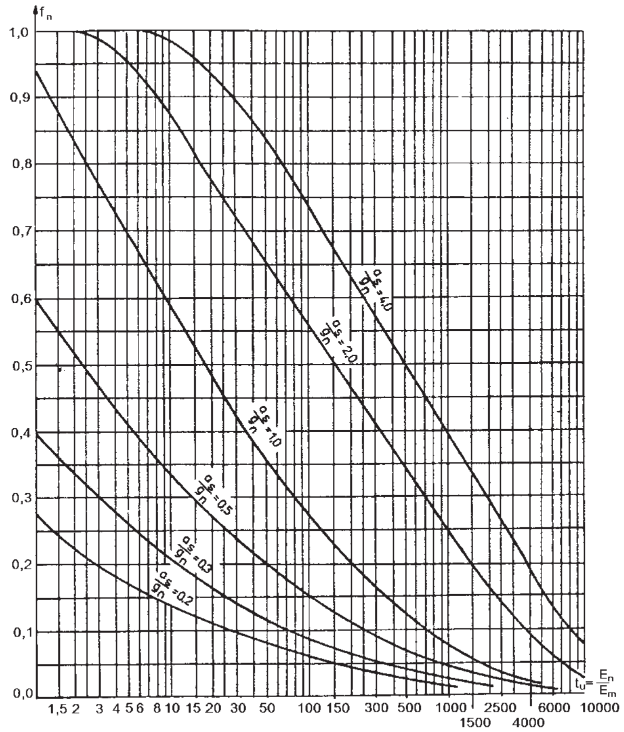

Fig. 8. The correlation between the coefficient f_n and the ratio values of $\frac{E_n}{E_m}$ and $\frac{a_s}{g_n}$

According to Figure 8 the values of a reducing coefficient f_n can be even lower than 0.1 in case of thick concrete pavements of higher values of modulus of elasticity E_n. This means, that over 90% of road traffic loads can be taken by the road surface. Thus, disregarding the reducing impact of the road surface in case of a load capacity analysis of sewers, especially of those laid shallow under the road surface, as well as in case of designing of the liners used for its reconstruction can lead to significant increase in the values of these loadings.

5. The consequences of using simplified methods for example scandinavian methodology of calculating the traffic loads

Presented below is the comparison of two methods – Scandinavian and KA-17.

Figure 9 shows the graph recommended by Scandinavian method for establishing vertical traffic loads expressed as a function of a depth of sewer.

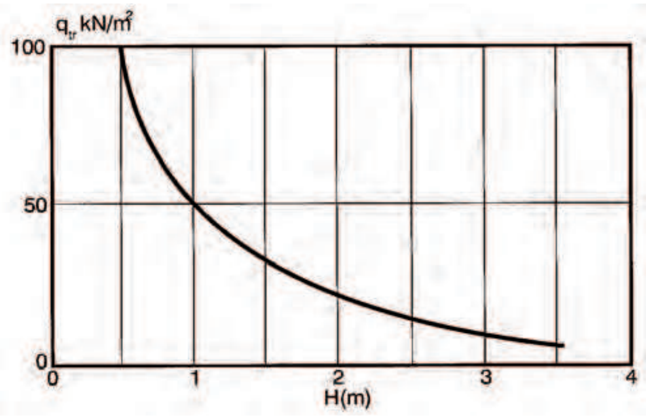

Fig. 9. Vertical loadings due to wheeled traffic as a function of a depth of sewer recommended by Scandinavian method.

Using the above graph it's possible to determine the average values of loadings for pipes which diameter is up to 0.5 m. The curve in Figure 9 includes a dynamic coefficient of 1.75 which further decreases as a result of the increase in the depth of sewer and finally reaches the value of 1.0 at the depth of 6.0 m.

The above methodology of calculating the traffic load values:

- does not allow to establish the values of loadings on one's own in case of pipes of more than 0.5 m in diameter as well as laid deeper than 3.5 m. Following the recommendations given in [3] it is necessary to contact the producer of pipes and ask for the values of these loadings;
- includes a false assumption that a dynamic coefficient decreases with an increase in the depth of sewer which is inconsistent with the physical lows there is no information available about the function describing the tendency for its decreasing. Such information would allow to determine the traffic load values without a dynamic coefficient;
- it disregards the influence of a pipe diameter, a type of soil and a type of vehicles on the traffic load values.

In Table 2 two different methods – Scandinavian and KA-17 are compared with regard to assuming the traffic load values. According to Table 2 the values of loadings determined for KA-17 method are between 74% and 264% of the value calculated according to Scandinavian method if *h* = 0.5 m. If *h* = 1.0 m they are between 53% and 202%. During calculations of loadings for sewers laid shallow below the ground level it is possible to oversize the thickness of sewer construction if only Scandinavian method is applied as well as to design the construction of 200% less than required load capacity. In case of sewers which load capacity is too low there is a risk that the sewer will collapse.

Table 2. Comparative calculation of traffic load values according to Scandinavian and KA-17 methods

The pipe diameter *d* (mm)	The pipe cover *h* (mm)	The type of ground	The loadings due to traffic multiplied by dynamic coefficient [kN/m²]		
			according to Scandinavian method	according to KA-17 method	
				for vehicle of 300 kN in weight and f_d = 1.2	for vehicle of 100 kN in weight and f_d = 1.5
100	0.5	highly cohesive	100	62×1.2 = 74.4	52×1.5 = 78
		non-cohesive non-compacted	100	220×1.2 = 264	175×1.5 = 262.5
100	1.0	highly cohesive	50	22×1.2 = 26.4	18×1.5=27
		non-cohesive non-compacted	50	84×1.2 = 100.8	60×1.5 = 90

6. Conclusions

1. The presented “KA-17” method for calculating a road traffic loads enables to determine their values as a function of depth of sewer, sewer diameter, type of soil above the sewer, type of land use above the sewer (the area beyond the road zones, roads opened to heavy traffic or to light traffic). The above methodology allows to make a proper calculations of road traffic loads acting on sewers of between 100 and 3000 mm in diameter and laid at 0.5 to 8.0 m below the surface. Taking into consideration the influence of a type of soil on the road traffic load values is a innovation of this method. The attached curves indicate how important for the values of these loadings the type of soil could be.
2. In the case of analyses of a safety coefficient of existing sewers as well as in case of designing the new pipes or linings used for pipe rehabilitation it is important to determine the correct dynamic and reducing coefficients values. As previously showed, they could have significant influence on the evaluation of the values of the final traffic load for static and load capacity.

References

[1] Kuliczkowski A.: *The traffic loads acting on pipelines and sewers laid in the ground*, Gas, Water and Sanitary Technique, 1988, No 11-12, pp. 250-252.
[2] Kuliczkowski A.: *Constructional designing of sewage pipes*, textbook No. 287, Kielce University of Technology, Kielce 1996.
[3] Kuliczkowski A.: *The sewage pipes*, vol. II, Constructional designing, monograph No. 42, Kielce University of technology, Kielce 2004, p. 507.
[4] Kubicka U. and others: *The problems of design, installation and exploitation of installation systems made of plastic pipes*. Static calculations, Information INSTAL, 1999, No. 2, p. 39-44.

Andrzej Kuliczkowski
Emilia Kuliczkowska
Anna Parka

Obciążenia użytkowe od taboru samochodowego w projektowaniu bezwykopowej odnowy przewodów kanalizacyjnych

1. Wstęp

Aktualnie, projektując konstrukcje przewodów kanalizacyjnych, często popełnia się szereg błędów związanych z ustalaniem wartości obciążeń użytkowych od taboru samochodowego. Jednocześnie zalecane metody obliczeniowe znacząco różnią się między sobą. Poniżej dokonano przeglądu istniejących metod, wskazując na różnice między nimi. Zaprezentowano także własną oryginalną metodę (KA-17), która po raz pierwszy przy ustalaniu wartości obciążeń użytkowych od taboru samochodowego uwzględnia rodzaj gruntu, przez który obciążenia przekazywane są od kół pojazdów w kierunku do wierzchołka konstrukcji kanałowej.

2. Problemy związane z ustalaniem wartości obciążeń użytkowych od taboru samochodowego w projektowaniu bezwykopowej odnowy przewodów kanalizacyjnych

Dotychczas przy obliczaniu wartości obciążeń użytkowych od taboru samochodowego posiłkowano się wzorem Boussines’a, w którym uwzględniony jest tylko nacisk od koła na nawierzchnię oraz parametry geometryczne miejsca, w którym obciążenia te są obliczane.

W zaproponowanej metodyce uwzględnia się także rodzaj gruntu, przez który obciążenia te są przekazywane na konstrukcję przewodów kanalizacyjnych. W oparciu o opisaną metodykę opracowano krzywe obciążeń, kolejno dla samochodów o ciężarze 100 kN, 150 kN i 300 kN oraz dla ciągnika kołowego o ciężarze 800 kN. Krzywe te opracowano dla przewodów o średnicach 0,1, 0,5, 1,0, 1,5, 2,0 i 3,0 m oraz pięciu różnych rodzajów gruntu, poczynając od gruntów niespoistych nie zagęszczonych, a kończąc na gruntach silnie spoistych.

Opracowane wykresy pokazano na rysunkach 3-7. Analizując te wykresy można dostrzec bardzo istotny wpływ rodzaju gruntu na wartość obciążeń użytkowych.

Następnie wskazano na błędy w zakresie ustalania wartości współczynnika dynamicznego, porównując wcześniejsze polskie zalecenia w tym zakresie oraz obecne zalecenia metod: niemieckiej, szwajcarskiej i skandynawskiej. Zwrócono także uwagę na pomijany w tych metodach bardzo znaczący wpływ nierówności drogowych na wartość współczynnika dynamicznego.

Żadna z dotychczas stosowanych metod projektowania powłok używanych w bezwykopowej odnowie przewodów kanalizacyjnych nie wspomina o odciążającym oddziaływaniu nawierzchni ulicznych. Na rysunku 8 zamieszczono krzywe umożliwiające ustalenie stopnia redukcji tych obciążeń (często bardzo znacznego) w wyniku przejmowania ich przez nawierzchnie uliczne. Ponieważ specyfiką metod bezwykopowych jest niewykonywanie wykopów (a tym samym nie usuwanie nawierzchni ulicznej na czas robót), stąd też przy ustalaniu wartości obciążeń użytkowych należałoby uwzględniać w toku obliczeń powyższy współczynnik. Nie powinien on być stosowany w tradycyjnych technologiach wykopowych.

W końcowej części artykułu porównano najbardziej niedoskonałą ze stosowanych obecnie metod, tj. metodę skandynawską z metodą KA-17, wskazując jak duże błędy popełniane są w wyniku jej stosowania.

3. Uwagi końcowe

Z uwagi na duże rozbieżności w zaleceniach analizowanych metod, dotyczących ustalania wartości obciążeń użytkowych od taboru samochodowego oddziałujących na konstrukcję przewodów kanalizacyjnych, wskazane jest:

a) wykonanie badań poligonowych celem weryfikacji założeń tych metod,
b) opracowanie europejskich wytycznych dotyczących ustalania wartości obciążeń użytkowych oddziałujących na konstrukcję przewodów kanalizacyjnych.