10.2478/v10160-011-0013-z

Transactions of the VŠB – Technical University of Ostrava

No.1, 2011, Vol.XI, Civil Engineering Series

paper #13

Jaroslav SOLAŘ[1]

PROTECTING UNDERGROUND LINE NETWORKS AGAINST LEAKAGE OF METHANE FROM SUBSOIL

Abstract

Methane occurs on the earth surface, usually in undermined areas, in particular, in locations where mines have been abandoned. Underground line structures can be protected against leakage of methane by coating insulation made from a suitable polymer film. This contribution proposes insulation against infiltration of methane into underground line structures (e. g. into shafts, reservoirs, silos, water reservoirs etc.)

Keywords

Undermined area, methane, subterranean line buildings, isolation against infiltration of methane.

Abstrakt

Metan se vyskytuje na zemském povrchu zpravidla na poddolovaném území, zejména v lokalitách, kde již bylo hlubinné dobývání ukončeno. Ochranu podzemních liniových staveb proti pronikání metanu z podloží zajistíme povlakovou izolací z vhodného typu polymerní fólie. Příspěvek pojednává o problematice návrhu izolace proti pronikání metanu z podloží do podzemních liniových staveb (např. kolektorů, šachet, jímek, zásobníků, vodojemů apod.).

Klíčová slova

Poddolované území, metan, podzemní liniové stavby, izolace proti pronikání metanu.

1 INTRODUCTION

Underground line structures include, in particular, combined utilities, shafts (for valves, for instance, reservoirs, bunkers or tanks. **Below are general requirements applicable to the underground line structures:**

1. Static aspects

2. Water insulation

3. Protection against methane leakage

This paper will discuss only the protection against methane leakage.

2 REQUIRED PROTECTION AGAINST METHANE LEAKAGE

Methane exists on the earth surface generally on undermined territories, mainly on sites where the underground mines have been abandoned. Typical sources of the methane are the abandoned mine workings without ventilation where the mine gas penetrates through the permeable overlying

[1] Doc. Ing. Jaroslav Solař, Ph.D., Katedra pozemního stavitelství, Fakulta stavební, VŠB-Technická univerzita Ostrava, Ludvíka Poděště 1875/17, 708 33 Ostrava - Poruba, tel.: (+420) 597 32 1301, e-mail: jaroslav.solar@vsb.cz.

strata onto the earth surface. In accordance with ČSN 73 0039 [1], the undermined territories are the sites within the effects of the underground mining. The problem is that the mixture of the methane and air may create an explosive or flammable concentration. The explosive concentration of the methane ranges between 5 and 15 %, depending on the contents of the gas in the air mixture.

3 COATED INSULATION AGAINST THE LEAKAGE OF METHANE FROM SUBSOIL

Coated insulation made from a suitable polymer foil can be used to protect the underground line structures against leakage of methane. The coated insulation is applied onto all structures that are in contact with the subsoil, this means, along the perimeter of the structure. The coated insulation reduces dramatically diffusion of methane through contact structures into a building. The degree of protection depends on the diffusion coefficient D [$m^2.s^{-1}$] for methane.

It is also necessary to ensure the minimum necessary air exchange in the underground facility, this means $n_{min,N} = 0.1\ h^{-1}$. Otherwise, methane could start cumulating inside the underground facility. **Below are principles applicable to the coated insulation which protects against the leakage of methane from subsoil:**

1. **If the structure is located on the undermined territory,** the project should provide reasonable resistance of the anti-methane insulation against undermining effects in line with ČSN 73 0039 [1].
2. **Methane insulation is also water insulation.** This means, the insulation should comply with ČSN P 73 0606 [4] and ČSN P 73 0600 [3].
3. **Insulation is made from a suitable polymer foil.** The insulation thickness needs to be calculated (see Chapter No. 3. 1).

Having measures the methane diffusion coefficient, **D_m [$m^2.s^{-1}$]**, the following conclusion can be drawn:

- Best materials appear to be PE-HD (High Density Polyethylene) or PP (Polypropylene) foils. The reason is that the methane diffusion coefficients, **D_m [$m^2.s^{-1}$]**, for these foils are very low.

Table 1 provides examples of the methane diffusion coefficients, D_m, for some materials.

The insulation material must fulfil following requirements.

a) **The required diffusion coefficient of the methane Dm [$m^2.s^{-1}$] must be fulfilled both for the area and for the joint.** In case of insulation foil systems it is not allowed to replace the welded joints with self-adhesive tapes the tightness of which might not prevent the methane from penetration.
b) **The elongation at break of the insulation material must be such** so that the insulation would be able to transfer the boundary deformations as set out in ČSN 73 1001 [6] for the specific type of the construction.If the structure is subject to the undermining effects, the insulation must be able to transfer the deformation resulting from the undermining, if the structure is protected with a yielding or mixed system pursuant to ČSN 73 0039 [1]. If a rigid system is used, this will not be an issue.
c) **The service life of the insulation material** must correspond to the expected service life of the structure.
d) **The insulation material must meet all requirements resulting from the specific conditions on the site** (the resistance against the mechanical load, corrosion load, …).

10.2478/v10160-011-0013-z

Table 1: Methane diffusion coefficient - D_m

Izolace			$D\ [m^2s^{-1}]$	
Název	Výrobce - dodavatel	Typ	Plocha	Spoj
Asfaltové pásy				
FOALBIT AL - SR S 40	Icopal, s. r. o. Praha		3,877.10◆	3,108.10◆
FOALBIT AL - S 40	Icopal, s. r. o. Praha		1,196.10◆	7,539.10◆
Paraplast M PV S 50-15 AB	Parabit Technologies, s. r. o. Zbuzany		5,814.10◆	1,194.10◆
Fólie				
Penefol 950	Lithoplast, s. r. o. Brno	PEHD	3,461.10◆▯	$4,223.10^{-12}$
Junifol	Juta, a. s. Dvůr Králové	PEHD	$3,27.10^{-12}$	
Oldroyd	Oldroyd systemer A/S, 3766 Sannidal Norway, do ČR dováží: Izohelp, s. r. o. Liberec	PP	8,147.10◆▯	4,806.10◆▯
Penefol 800	Lithoplast, s. r. o. Brno	PELD	2,35.10◆▯	neměřeno
Fatrafol 803	Fatra Napajedla	mPVC	$4,617.10^{-10}$	4,538.10◆
R-fol 950	PK IZOLACE, s. r. o. Herálec	PEHD	$3,51.10^{-12}$	$9,42.10^{-12}$
R-fol 900	PK IZOLACE, s. r. o. Herálec	PEHD	$1,01.10^{-11}$	$1,15.10^{-11}$
R-fol 800	PK IZOLACE, s. r. o. Herálec	PEHD	$1,11.10^{-11}$	$3,59.10^{-11}$
Fatrafol 806	Fatra Napajedla	mPVC	$4,05.10^{-12}$	$9,35.10^{-12}$
F 635-15	Sarnafil	mPVC	$2,16.10^{-11}$	$6,16.10^{-11}$
G 476-15	Sarnafil	mPVC	$4,01.10^{-11}$	$5,74.10^{-11}$
TG 68-20	Sarnafil	mPVC	$1,87.10^{-11}$	$2,73.10^{-11}$
Cementová malta				
Cementová malta (těžené kamenivo)			$7,64.10^{-5}$	αΝπαφ
Cementová malta (drcené kamenivo)			$3,63.10^{-6}$	◆ ▯

4. When **passing though the insulation**, **steel shell pipes with welded fixed flanges** must be provided in order to prevent the methane from penetration: the hydro-insulating coat will be pressed between the fixed and loose flanges. The space between the shell pipe and the protruding pipe or cable will be filled in with a suitable gas-proof sealing (such as a permanent flexible binding agent or rubber profiles). Same principles apply as for the radon insulation - see Chapter 6.8 in ČSN 73 0601 [5].
5. **Under the horizontal insulation, a underlying layer is placed** - underlying concrete (C 12/15 concrete with the minimum thickness of 100 mm.
6. **In undermined territories,** a sliding joint pursuant to ČSN 73 0039 [1] or a rheological sliding joint might be introduced into the underlying concrete in order to reduce joint stress in the foundation bottom. It is possible to decrease the shear stress in the foundation bottom and under the underlying concrete, to a certain extent, by introducing a suitable separation layer, such as a geo-textile under the underlying layer straight on earth or onto a gravel-sand cushion.
7. **The underlying concrete is cast either:**
   a) directly onto natural ground – because of ground water if the subsoil is pervious;
   b) onto a gravel-sand cushion – if groundwater cannot penetrate through subsoil (the permeability coefficient for soil is $k \geq 1.10^{-4}$ $m.s^{-1}$ – see ČSN P 73 0600 [3]. The thickness of the gravel-sand cushion is 200 mm at least. Humidity and evenness of

the underlying layer must be chosen depending on the used insulation material. Parameters are typically specified by the manufacturers.

8. **Construction, acceptance and protection of the insulation** is, typically, governed by same principles as the water insulation.
9. **When applying the coated insulation it is recommended** to back up the underground structures with soil and to cover the ground structures with high gas permeability materials, for instance gravel soil or sand soil, G1, G2, G3, S1, S2, S3 classes pursuant to ČSN 73 1001 [6].
10. If possible, **materials with low gas permeability** (such as asphalt or concrete) **should not be used, in big areas or for landscaping, above the underground structures and in close neighbourhoods.**
11. **For air exchange, a ventilation turbine should be installed into a ceiling of the underground structure.** See Fig. 1. The air turbines should be installed, in particular, in places where the direction changes. Maximum distances between the air turbines will depend on the size of the air turbines.

Air flow velocity can be increased, for instance, by ventilation turbines (Lomanco, for examples) to be installed at certain distances from each other. Wind blowing will make the air turbines to revolve. In turn, air turbine revolutions will make the air in the combined network to flow. Currently, air turbine with integrated fans are available - they perform well even if the wind velocity is very low or zero (according to statistic data, there is no wind in the Czech Republic for almost three months a year). Total costs for energies consumed by fan drives are minimum.

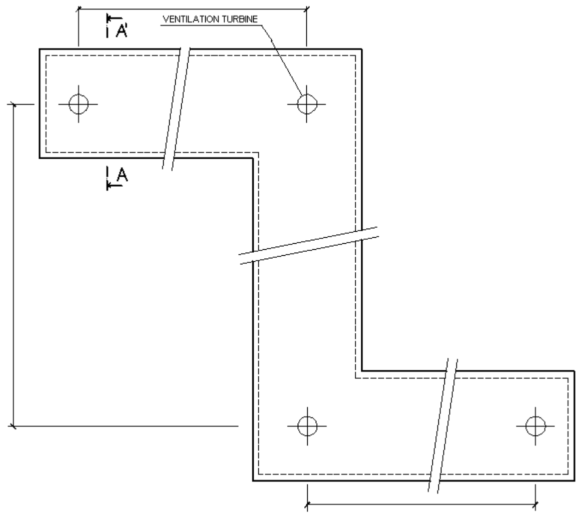

Fig. 1: Exapmle of floor plan of ventilation turbine in shaff

3.1 Sizing the thickness of the coated insulation against methane leakage

The type and thickness of the coated insulation against methane leakage depends on the requirements above. This means, all specific aspects should be taken into account and a comprehensive evaluation is necessary.

The thickness of the coated insulation can be calculated using the procedure below which was developed on the bases of [9] where the formulae (2) and (4) were mentioned.Using this method it is possible to design the minimum necessary thickness of the insulation, $b_{min,}$ [m] so that the methane weight flow intensity, Q_m, through the insulation into the underground structure were less than the maximum permitted weight flow intensity, $Q_{m,\ max}$.

a) The minimum necessary thickness of the insulation, $b_{min.}$ [m] , against methane leakage is obtained from:

$$b_{min.} = D_m \cdot \frac{A \cdot (v_1 - v_2)}{n \cdot V \cdot v_2} \qquad \textbf{[m]} \qquad \textbf{(1)}$$

where: D_m [$m^2.s^{-1}$] – the methane diffusion coefficient

v_1 [%] – the concentration of methane leaving the subsoil

v_2 [%] – the maximum permitted concentration of methane downstream the insulation (inside the structure)

A [m^2] – the total area of the structure which is in contact with the subsoil – see formula (3),

V [m^3] – the total volume of the room

n [s^{-1}] – intensity of infiltration ventilation in the room

The values below are substituted in (1):

– **$v_2 = 1.10^{-3}$** , this means **0.1 %** (see Chapter 1).

– **v_1** will be replaced with **100 %**. (The calculation will be on the safe side).

– **D_m [$m^2.s^{-1}$]** will be chosen for a specific insulation material. The value to be used will be the worse one (i.e. the higher one) from the values measured in the surface and in the joint.

– For safety reasons, **= 0.05 h^{-1} (n = 1.39 . 10^{-5} s^{-1})**. This means, the value will be a half of $n_{min,a}$ = 0.1 h^{-1}.

The total area of the structure which is in contact with the subsoil, A [m^2], is calculated as follows:

$$\mathbf{A = A_p + A_s + A_{strop}} \qquad \textbf{[m}^{-2}\textbf{]} \qquad \textbf{(2)}$$

where: **A_p** [m^2] – the surface of the floor which is in contact with subsoil

A_s [m^2] – the total area of all walls which are which in contact with adjacent soil

A_{strop} [m^2] – the total area of ceiling of the underground room.

Note:

1. Methane density is lower than air density and it is not likely that the methane would diffuse into underground structures through ceilings. Nevertheless, the ceilings should be provided with gravity water insulation. It is recommended that the material for water insulation of the ceiling would be same as that for the floors and walls.

2. Partial diffusion through ceilings cannot be, however, entirely excluded, for instance, in places where impermeable layers (asphalt or concrete) are placed above the underground structure because methane could cumulate under that layer.

3. Including the ceiling area into calculation, a safety margin will be created.

b) The time, t_k [s], during which the methane concentration goes up beyond the critical methane concentration, $v_{2,krit.}$ = 4 %, can be calculated from the following formula:

$$t_k = \frac{V \cdot b}{D_m \cdot A} \cdot \ln \frac{v_1 - v_2}{v_1 - v_{2,krit.}} \qquad \textbf{[s]} \qquad \textbf{(3)}$$

where: b [m] – the designed real insulation thickness,

$v_{2,krit.}$ [%] – the critical concentration of methane $v_{2,krit.}$ = 4 % is always substituted there

Description of other quantities is given in (1).

10.2478/v10160-011-0013-z

The time, t_k , is calculated with the assumption that ventilation intensity is n = 0.

The following condition must be fulfilled:

$$t_k \geq 30 \text{ days} \quad (4)$$

3.2 Examples – designing the coated insulation against leakage of methane from subsoil

a) An underground room (e.g. a valve chamber)

Let us assumed a new valve chamber in a public water mains. For the ground plan see Fig. 2. For the cross-section see Fig. 3. The facility is located under the ground. Height levers are indicated in Fig. 3. The facility will be ventilated through a ventilation turbine located in an adjacent combined network which is connected to the valve chamber.

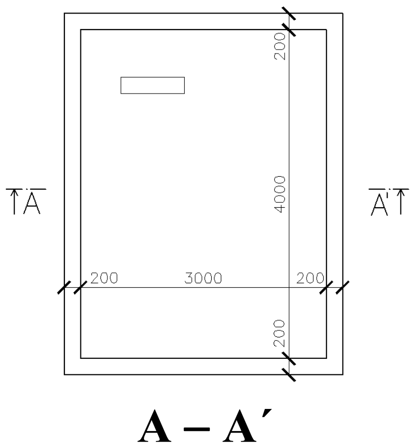

Fig. 2: Floor plan of underground structure gatehouse

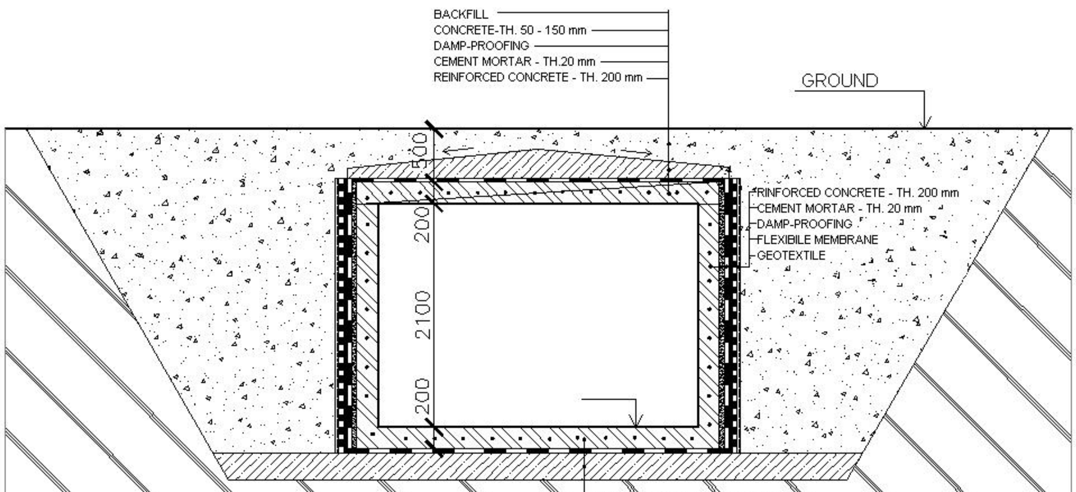

Fig. 3: Cross-section, A-Á

1. **Let us calculate the basic geometric characteristics:**

The total volume of the underground room: $\mathbf{V = 3.0\ .\ 4.0\ .\ 2.1 = 25.2\ m^3}$

The total area of the structures which are in contact with the subsoil:

$\mathbf{A = A_p + A_s + A_{strop} = 2.(3.0\ .\ 4.0 + 3.0\ .\ 2.1 + 4.0\ .\ 2.1) = 53.4\ m^2}$

2. **Let us calculate the minimum necessary thickness of the insulation, b [m]:**

The calculated ventilation intensity: $\mathbf{n = 0.05\ h^{-1} = 1.39.10^{-5}\ s^{-1-}}$

$\mathbf{v_1 = 1.0}$

$\mathbf{v_2 = 0.001}$

The proposed polymer foil – PE-HD Penefol 950: The diffusion coefficient for methane, D_m, is (see Table 1):

a) In the foil surface (without the joint) – $\mathbf{D_m = 3.461.10^{-12}\ m^2.s^{-1}}$,

b) In the joint– $\mathbf{D_m = 4.223.10^{-12}\ m^2.s^{-1}}$.

$$b_{min.} = D_m \cdot \frac{A \cdot (v_1 - v_2)}{n \cdot V \cdot v_2} = 4{,}223.10^{-12}.\frac{53{,}40.(1-0{,}001)}{1{,}39 \cdot 10^{-5} \cdot 25{,}2 \cdot 0{,}001} = 6{,}43.10^{-4}\,m = 0{,}7mm$$

We will choose the nearest higher available thickness of Penefol 950: **b = 0.8 mm.**

Note: Because the methane insulation is also water insulation it will be necessary to compare the thickness of water insulation foil with that of water insulation foil for a specific hydro-physical load pursuant to ČSN 73 0606 [4].

3. **The time, t_k [s], during which the methane concentration in the underground room goes up beyond the critical methane concentration, $v_{2,krit.}$ = 4 %, (when n = 0) is:**

$$t_k = \frac{V \cdot b}{D_m \cdot A} \cdot \ln\frac{v_1 - v_2}{v_1 - v_{2,krit.}} = \frac{25{,}2.0{,}8.10^{-3}}{4{,}223.10^{-12} \cdot 53{,}4} \cdot \ln\frac{1-0{,}001}{1-0{,}04} = 3\ 559\ 965\ \mathbf{s = 41.2\ days >}$$

30 days ⇒ the proposed foil thickness, b = 0.8 mm, **is compliant**

b) An underground combined network

Let us assume a new underground combined network for a distance heating pipeline. For the ground plan see Fig. 4. For the cross-section see Fig. 5. The facility will be ventilated through ventilation turbines.

10.2478/v10160-011-0013-z

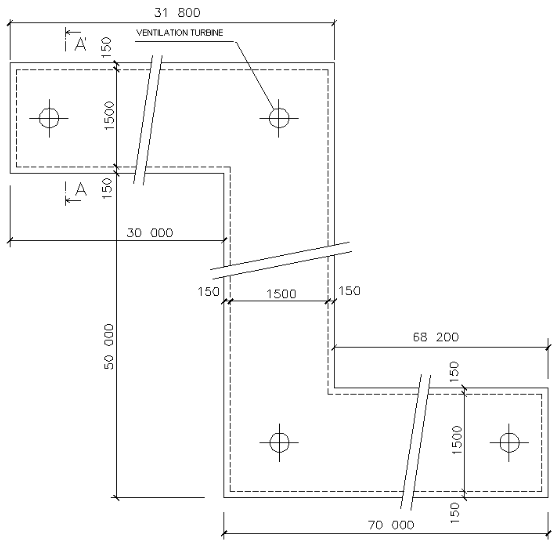

Fig. 4: Floor plan of shaft

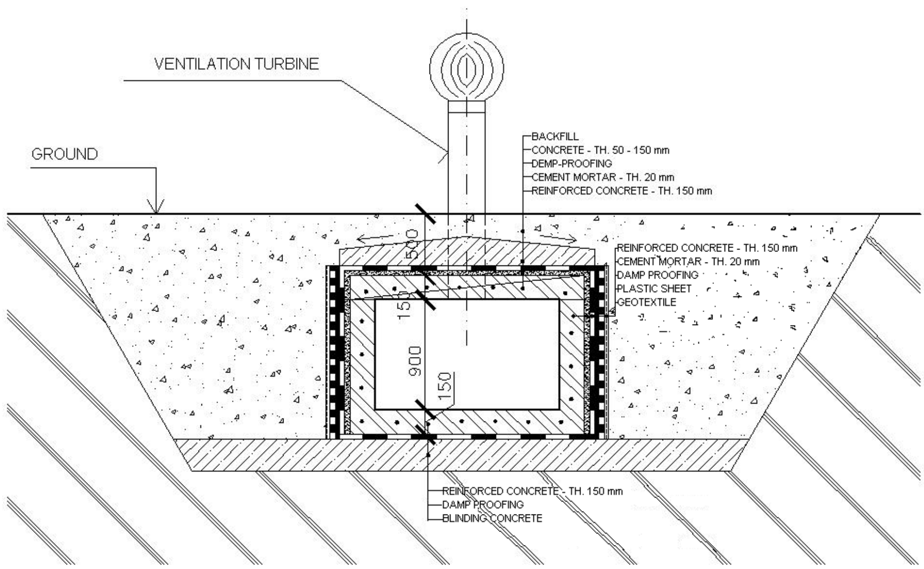

Fig. 5: Cross -section A-Á

1. Let us calculate the basic geometric characteristics:

The total volume of the underground combined network:

$$\mathbf{V = (31.5 + 48.5 + 69.7).\ 1.5\ .\ 0.9 = 202.1\ m^3}$$

The total area of the structures which is in contact with the subsoil:

$$\mathbf{A = A_p + A_s + A_{strop}}$$

$\mathbf{A_p = (31.5 + 48.5 + 69.7) . 1.5 = 224.6\ m^2}$

$\mathbf{A_s = (31.5 + 50.0 + 68.2 + 1.5 + 69.7 + 50.0 + 30.0 + 1.5) . 0.9 = 272.2\ m^2}$

$\mathbf{A_{strop} = A_p = 224.6\ m^2}$

$\mathbf{A = A_p + A_s + A_{strop} = 224.6 + 272.2 + 224.6 = 721.4\ m^2}$

2. **Let us calculate the minimum necessary thickness of the insulation, b [m]:**

The calculated ventilation intensity: $\mathbf{n = 0.05\ h^{-1} = 1.39 . 10^{-5}\ s^{-1-}}$

$\mathbf{v_1 = 1.0}$

$\mathbf{v_2 = 0.001}$

The proposed polymer foil - PE-HD Penefol 950: The diffusion coefficient for methane, D_m, is (see Table 1):

a) In the foil surface (without the joint)– $\mathbf{D_m = 3.461.10^{-12}\ m^2.s^{-1}}$,

b) In the joint– $\mathbf{D_m = 4.223.10^{-12}\ m^2.s^{-1}}$.

$$b_{min.} = D_m \cdot \frac{A \cdot (v_1 - v_2)}{n \cdot V \cdot v_2} = 4{,}223.10^{-12}.\frac{721{,}4.(1-0{,}001)}{1{,}39 \cdot 10^{-5} \cdot 202{,}1 \cdot 0{,}001} = 1{,}08.10^{-3}\,m = 1{,}1mm$$

We will choose the nearest higher available thickness of Penefol 950: **b = 1.3 mm**.

3. **The time, t_k [s], during which the methane concentration in the underground goes up beyond the critical methane concentration, $v_{2,krit.}$ = 4 %, (when n = 0) is:**

$$t_k = \frac{V \cdot b}{D_m \cdot A} \cdot \ln\frac{v_1 - v_2}{v_1 - v_{2,krit.}} = \frac{202{,}1.1{,}3.10^{-3}}{4{,}223.10^{-12} \cdot 721{,}4} \cdot \ln\frac{1-0{,}001}{1-0{,}04} = 3\ 434\ 234\ \mathbf{s}$$

i.e. 39 days > 30 days ⇒ the proposed foil thickness, b = 1.3 mm, **is compliant**

Note: Because the methane insulation is also water insulation it will be necessary to compare the thickness of water insulation foil with that of water insulation foil for a specific hydro-physical load pursuant to ČSN 73 0606 [4].

4 ADDITIONAL MEASURES IN CASE OF EXISTING UNDERGROUND FACILITIES

In case of the existing underground facilities where hazardous concentration of methane has been found, following measures need to be taken:

1. **An additional insulation should be laid on the bottom and external walls of the external walls in the underground facilities in order to prevent methane leakage.**
2. **After the ceiling is completed, the methane insulation should be also applied onto the ceiling – it should extend over vertical walls down to 500 mm at least.** See Fig. 6. Parameters of the methane insulation will be calculated (see above).
3. **A ventilation turbine (or turbines) will be installed into the ceiling.** The size and number of the turbine(s) will depend on the size of the underground facility.

It this is a combined underground line network, it is recommended to install the turbines also into bending points. See Fig. 4 and 6.

10.2478/v10160-011-0013-z

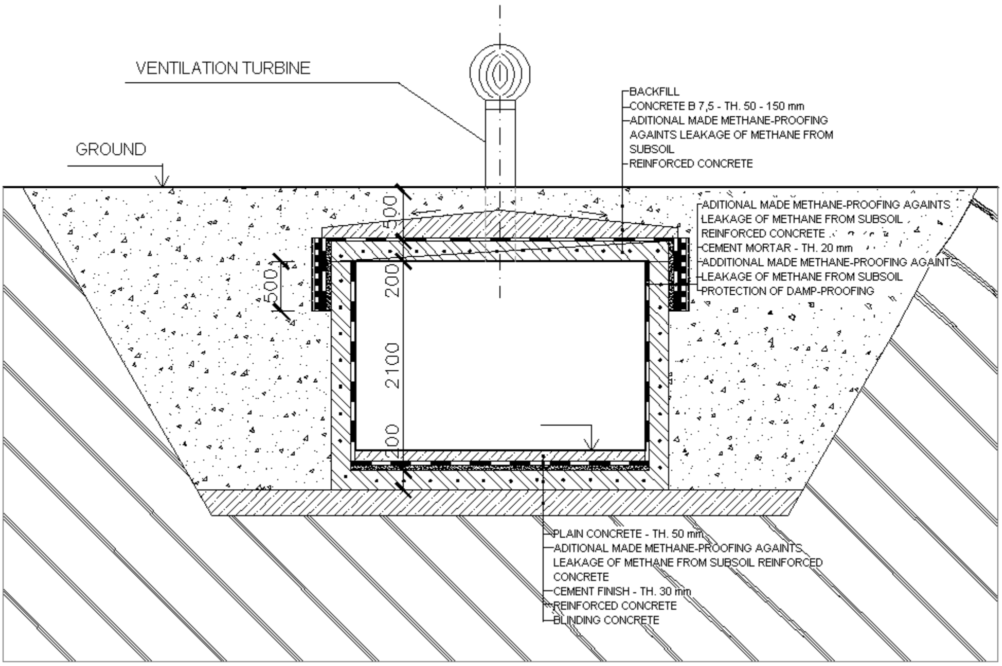

Fig. 6: Principle of structural design of incremontal building conversion by shaff

REFERENCES

[1] ČSN 73 0039 Navrhování objektů na poddolovaném území (1989).

[2] Bradáč J.: Účinky poddolování a ochrana objektů. Díl první. EXPERT – Technické nakladatelství Ostrava, 1996.

[3] ČSN 73 0600 Hydroizolace staveb – Základní ustanovení (2000).

[4] ČSN 73 0606 Hydroizolace staveb – Povlakové hydroizolace – Základní ustanovení (2000).

[5] ČSN 73 0601 Ochrana staveb proti radonu z podloží (2006).

[6] ČSN 73 1001 Základová půda pod plošnými základy (1987).

[7] ČSN 75 6101 Stokové sítě a kanalizační přípojky (2004).

[8] Bradáč J.: Účinky poddolování a ochrana objektů. Díl druhý. Dům techniky Ostrava, spol. s r. o., květen 1999. ISBN 80-02-01276-3.

[9] Blaha A., Fojtů D.: Metodika posuzování postačitelnosti protiplynové izolace proti pronikání metanu z podloží do stavebních objektů. Univerzita Tomáše Bati ve Zlíně, červenec 2003. Nepublikováno.

Reviewers:

Doc. Ing. Martin Jiránek, CSc., Faculty of Civil Engineering, Czech Technical University in Prague.

Ing. Michael Balík, CSc., Dehumidification of buildings, Prague.