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A STUDY OF THE STRENGTH OF COMPOSITE SHAFT LINING OF CONCRETE AND STEEL TUBBING

Summary. In this article, the authors present on the basis of stress and failure tests two different types of structures of composite shaft lining of concrete and steel tubbing and the analysis made on the loading state and mechanism of failure of composite shaft lining to show that composite shaft lining of concrete and double steel tubbing gives higher load-bearing capacity; while in the mean time points out problems existing in the designing methods of shaft lining currently used; and gives in the last part of this paper equations for calculating the ultimate load of composite shaft lining.

Introduction

In the construction of Huainan-Huaibei coal base of this country because the shaft size is large and the overburden is thick, the shaft lining structure is an urgent problem to be sloved. Composite shaft lining of concrete and steel tubbing is one of the shaft lining structures to be developed for deep shaft lining. But it lacks necessary research work both at home and abroad in the determination of the loading capacity of composite shaft lining, the deformation and failure state, the combined action of reinforced concrete RC and steel tubbing as well as the reasonable calculating method. To solve these problems, both experimental and theoretical studies on the composite shaft lining of RC and steel tubbing are urgently needed.

Experimental method of study

Test Structure Element of Shaft lining

The same materials are used for the test element as that of making shaft lining (fig. 1), its size depends on the loading device used.

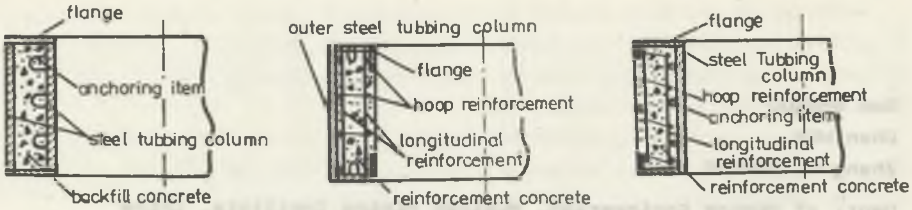


Fig. 1. The test element of the study

a) test structural element of composite shaft lining of concrete and steel tubbing, b) single outer tubbing, c) single inner tubbing

Rys. 1. Element próbny do badań

a) próbny element konstrukcyjny obudowy szybu o konstrukcji zespolonej z betonu i stalowego tubingu, b) pojedynczy tubing zewnętrzny, c) pojedynczy tubing wewnętrzny

Loading Devices

Loading devices consist of a hydraulic high strength shaft lining loading device and a shaft lining triaxial loading device. The hydraulic high strength shaft lining loading device mainly is composed of a tube, a top cover, a bottom cover and bolts. In testing, remove the top cover, hang up the test element and put in into the tube, replace the cover, tighten up all the bolts, then apply load. In the device, the test element receives the hydraulic pressure all around to simultate the drilled shaft lining being under the pressure of mud, soil and water. The top and the bottom surfaces of the test element are pressed tightly with the bolts. As the surrounding pressure of the test element increases, the positive stress induced in the test element increase due to the confinement that its longitudinal deformation is restrained, which is practically similar to the loading conditions of the shaft lining.

The triaxial loading device consists of a tube, a piston, a top cover, a bottom cover and bolts. The device features that the axial loading of the simulated shaft lining can be adjusted with different conditions to give the testing conditions as similar as the practical conditions. In testing, the axial loading is transmitted along the piston bar to the end of the test element by a YZ-200 A column presser. The simulated pressure that the shaft lining bears is the same as that of the surrounding hydraulic pressure given in the high strength shaft lining testing by the hydraulic loading device.

Measurement for the Testing

In the testing, the measured and the method used are as follows:

1. Loading Measurement

The loading is measured by means of two standard pressure gauges of Class 0.35 or 0.4 and an oil-transducer fixed to the high pressure loading device, and the strain data are recorded by a strain meter. The measuring error of the oil-transducer is 0.1 MPa.

2. Strain Measurement

The transducer element for strain measuring is an electric resistance strain gauge. The strain is measured by a combined system which consists of an YJD-17 digital strain meter and an APPLE-II micro-computer for timely collecting and processing static strain measurement data automatically.

In the course of thesting, the oil-transducer is used for monitoring the loading action, so that the error of constant pressure is kept in an allowable limit. The system, based on constant pressure conditions, can give collecting instruction at any time. When the instruction is given, the system immediately auto-collects the test data of specified order for the computer to process and give the output. The whole system is operated with man-machine dialogue and is controlled with the programming in advanced language.

The measuring points of strain are arranged on the surfaces of both inside and outside steel tubbings and on the surface of concrete of the test element; 4-8 sections are arranged circumferentially, and 2 or 3 measuring points are arranged for each section axially on the inside and outside surfaces of the test element so as to examine the surface action of the test element and check the measuring data of the same section by repetition.

As for the test element of composite shaft lining of RC and single steel tubbing, the strain measuring points on the inner reinforcement are arranged in a way corresponding to that of the measuring points on the inside and outside surfaces of the element. Generally four sections are arranged circumferentially, 2 or 3 measuring points are arranged axially for each section, two strain gauges are instelled, one is the measuring point ring and the other is one the vertical reinforcement.

To analyse the combined action of concrete and steel tubbing, four symmetrical sections are chosen circumferentially, strain gauges are installed on the inner steel anchors in order to measure the stress of the anchors.

3. Displacement Measurement

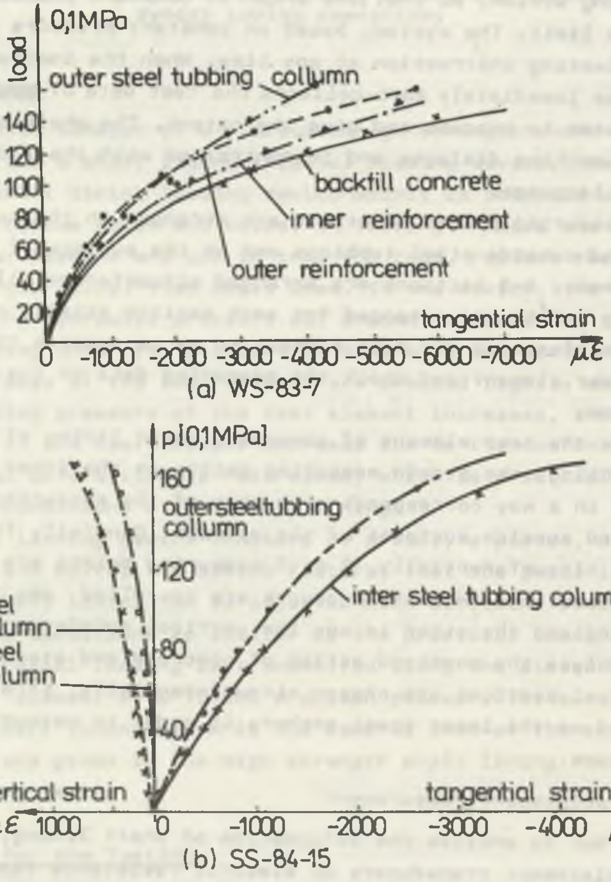
In order to analyse the deformation of shaft lining, 4 or 6 symmetrical displacement transducers of electric resistance type are installed radially on the inner rim of the shaft lining, when the hydraulic high strength loading device is used, the strains are measured with the above system for timely collecting and processing static strain measureement data.

Deformation characteristics and stress analysis of shaft lining

Characteristic of Deformation

While the composite shaft lining of RC and steel tubbing is subjected to loading, its section strain characteristics are:

The deformation can be devided into elastic and plastic stages. In the elastic stage the relationship between the section strain and the loading approximetely linear (fig 2) and the strain difference between the inner and outer layers is not great, generally it is linear distribution (fig.3). When the external loading is greater than 30-40% of ultimate strength, the shaft lining is in plastic state and the relationship curve of tangen-



(a) WS-83-7

(b) SS-84-15

Fig. 2. Load-strain curve of the test element of composite shaft lining of concrete and steel tubbing

Rys. 2. Wykres odkształceń jako funkcja obciążenia elementu próbnego zespolonej obudowy szybu z betonu i stalowego tubingu

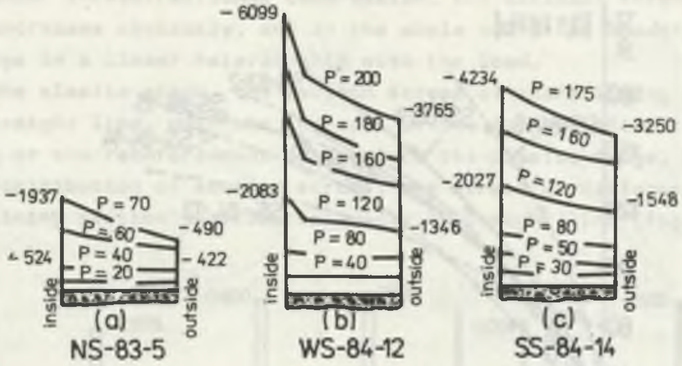


Fig. 3. Distribution of tangential strain on the shaft lining section
Rys. 3. Rozkład odkształceń stycznych w przekroju obudowy szybu

tial strain against the load bends obviously. As load increases, the strain also increases but much quicker, and the tangential strain of the section gradually becomes a curved distribution.

As the composite shaft lining of RC and double steel tubbing enters into the plastic state, the difference of tangential strain be between the inner and the outer rims is not great; while in the single tubbing composite shaft lining, the increase of this difference is obviously great (fig. 3). Therefore the combined action of single steel tubbing and RC is not obvious.

The equation for the radial displecement-load deformation curve of composite shaft lining (fig. 4) can be expressed as an exponential function in the following:

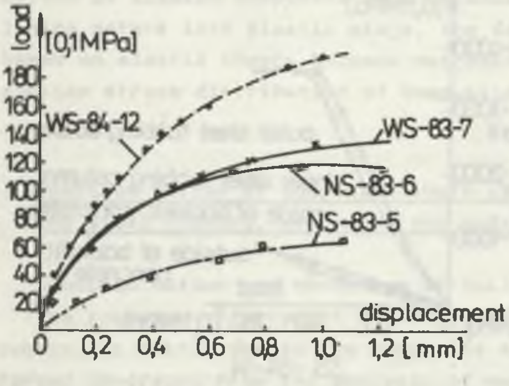


Fig. 4a. Load-displacement curve of composite shaft lining

Rys. 4a. Wykres przemieszczeń jako funkcji obciążenia zespolonej obudowy szybu

$$V = ap^b \qquad (b > 1)$$

Where a and b are constants to be determined from the test.

Stress Analysis

In the course of loading of the composite shaft lining, the change and distribution of the section strain can be illustrated with the stress-load curve and the distribution of section stress diagram.

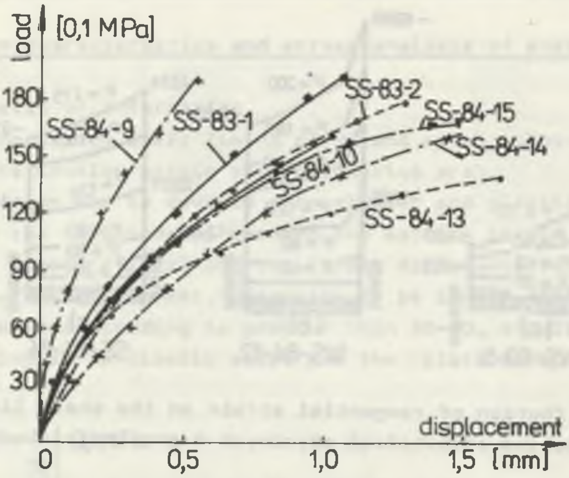
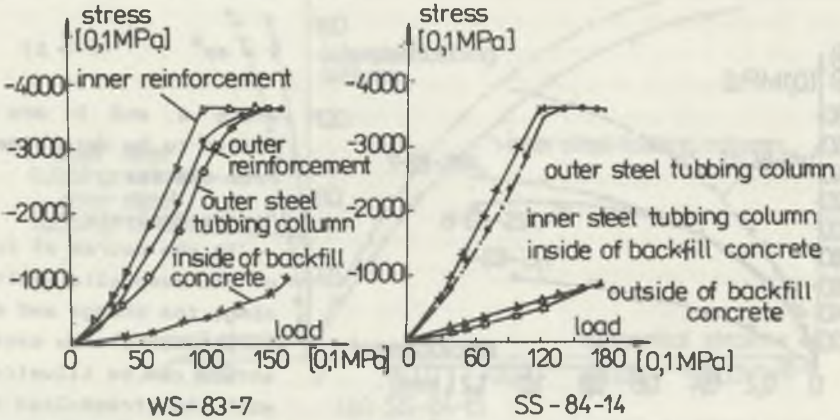


Fig. 4b. Double steel tubbing
Rys. 4b. Podwójny tubing stalowy

From the stress-load curve of the steel tubbing or the reinforcement, the process of loading of the composite shaft lining can be divided into two stages: the elastic stage and the plastic flow stage. As the shaft lining is in the three dimensional state of compression, the yield limit of the steel tubbing or the reinforcement increases to about a_3 = 3.200 x x 0.1 MPa from uni-directional stress a_3 = 2.4000 x 0.1 MPa. Before the apparent plastic deformation occurs in the steel or the reinforcement, the 6-p curve is approximately a straight line (fig. 5) and at the same



WS-83-7 SS-84-14

Fig. 5. Relationship between tangential stress and load of composite shaft lining

Rys. 5. Zależność pomiędzy naprężeniem stycznym i obciążeniem zespolonej obudowy szybu time, under threedirectional compression, the ultimate strength of concrete increases obviously, and in the whole course of loading, the stress is always in a linear relationship with the load.

In the elastic stage, the section stress of shaft lining distributes in a straight line. With the increase of the loading after the steel tubbing or the reinforcement enters into the plastic stage, because of the redistribution of section stress, the stress of different layers of shaft lining section distributes evenly a straight line (fig. 6).

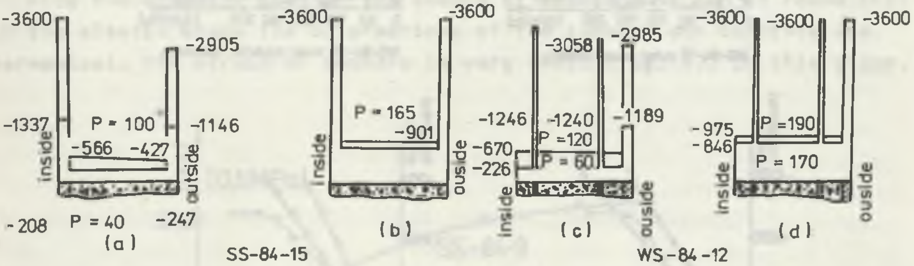


Fig. 6. Distribution of tangential stress of shaft lining
Rys. 6. Rozkład naprężeń stycznych w obudowie szybu

Generally, H. Link's designing method of West Germany and the elastic combined tube designing method given in this article by the authors are now used at home and abroad for theoretical calculation of the section stress of composite shaft lining of concrete and steel tubbing. Comparison of the testing result with the theoretical calculation (fig. 7), it shows that the calculation of composite shaft lining of concrete and steel tubbing for the stress in elastic stange is reasonable when the method of elastic composite tube calculation is used. But when the shaft lining enters into plastic stage, the designing or the calculating method based on elastic theory becomes not suitable for the description of the section stress distribution of composite shaft lining.

Combined action of composite shaft lining of concrete and steel tubbing, mechanism and mode of failure

Combined Action and Mechanism of Failure

The increase of strenght of composite shaft lining by double steel tubbing is mainly due to the composite action of steel tubbing and reinforced concrete. From the analysis of macromechanics, the inner and outer steel tubbings exert a hooping and confining action on the concrete between, so that the concrete is subjected to three-directional loading, therefore the strength of concrete is apparently increased. The test shows

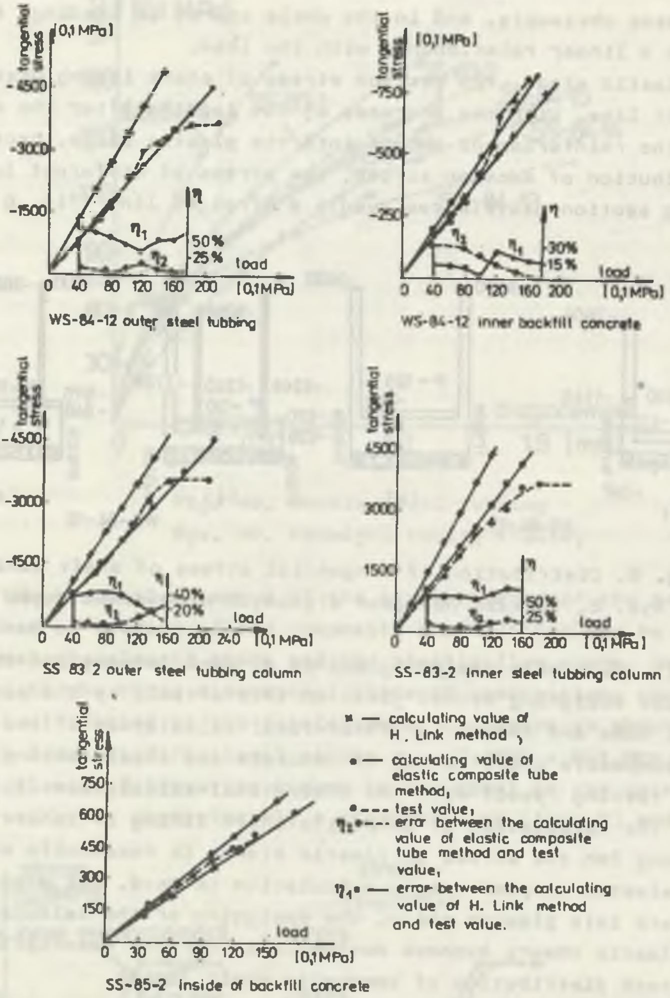


Fig. 7. Comparison of test results of section strain of shaft lining with calculated results obtained from present designing methods

x - calculation value of H, Link method, ● - calculation value of elastic composite tube method, O - test value, η_2o - error between the calculation value of elastic composite tube method and test value, η_1o - error between the calculating value of H, Ling method and test value

Rys. 7. Porównanie wyników badań odkształceń przekroju obudowy szybu z wynikami obliczeń otrzymanymi z aktualnych metod projektowania

x - wartośc obliczeniowa H, metoda węzłów, ● - wartość obliczeniowa w metodzie sprężystej rury zespolonej, O - wartość otrzymana w doświadczeń (prób), η_2o - błąd między wartością obliczeniową w metodzie elastycznej rury zespolonej i wartością doświadczalną, η_1o - błąd między wartością obliczeniową H w metodzie węzłów i wartością doświadczalną that the ratio of greatest tangential stress to the standard axial compressive strength of the rhombohedron, or the so-called "strength" increased coefficient of RC being in 2 to 5. In addition, the anchors, welded on the inner steel tubbing, give an action just like fixing many tension rods around the steel tubbing. In this way the reinforced concrete between will act an anchoring action on the inner steel tubbing which is prevented from being bent or losing stability and increase the load-baring capacity.

From the analysis made on the course of loading, it can be found that in the elastic stage the deformations of the tubbing and concrete are harmonical. The strain of anchors is very small (fig. 8). In this stage, the combined action of the steel tubbing and concrete is not obvious. When the inner steel tubbing is in plastic stage, the transversal deformation coefficient of concrete approximates to or keeps up with that of steel tubbing, and the strain of anchors remarkably increases. At this time, the concrete is under compression, obviously its strenght increases, and its tangential stress reaches or surpasses the axial compressive strength R_a^b without causing failure. In the meanwhile, because of the action of anchors and the confining of concrete between, the tangential stress of the inner steel tubbing serpasses the yield limit, but no failure occurs. As loading keeps on increasing, the plastic deformation of the steel increases, and reaches strengthening stage. At this time the value of the transvelsal deformation coefficient of the concrete exceeds

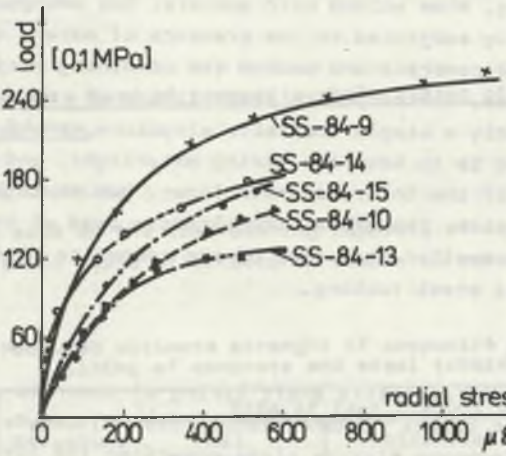


Fig. 8. Relationship between the loading of composite shaft lining and the strain of inner steel anchors

Rys. 8. Zależność między obciążeniem zespolonej obudowy szybu i odkształceniem wewnętrznych kotew stalowych that of the steel by more than 0.5, the strain of the anchor increases rapidly, and the tangential stress of the concrete exceeds R_a^b remarkably. As the hooping action of steel tubbing still exists, this will continue to strengthen the concrete between. As the loading continues to increase to reach the plastic state, the increased loading will be completely taken by the concrete between and will increase the stress of the concrete more rapidly. When the external loading approaches is yield limit, a part of the inner steel tubbing between the anchros will firstly fold, or a part of the concrete in contact with the anchors will deform greatly, thus leading to the failure of the shaft lining.

The same combining action exists in the shaft lining of RC and single inner steel tubbing, when welded with anchors. But owing to the outer concrete is directly subjected to the pressure of water, this will reduce the strenght of the concrete and weaken the combining action of the steel tubbing and concrete. The composite shaft lining of RC and single outer steel butting is only a simple composite structure, the fuction of the outer steel tubbing is to keep the lining watertight, and improves the working condition of the inner concrete liner, but it lacks the above good combined function. Therefore, the ultimate load of these two types of shaft lining is smaller than that of the composite shaft lining of concrete and double steel tubbing.

Mode of Failure

Mode of failure of composite shaft lining of concrete and double steel tubbing is: plastic convex flexure plano (folding) occurs on the inner steel tubbing and concave flexure plane occurs on the outer steel tubbing, while the concrete between the linner and the outer steel tubbing breaks in the direction of the bending of the inner and outer tubbings by compression and shearing along an inclined section. The breaking plane is at an angle of 30^o-40^o with the greatest compressive stress.

From an analysis made on the mode of flexure plane of the inner steel tubbing, there are two types of mode of failure:

1. When the load approaches to the ultimate strength, firstly longitudinal flexure occurs somewhere between two rows of anchros in the inner steel tubbing causing instability, the state of stress of that part of concrete in contact with the flexure changes from three-dimensional compression to two dimensional compression thus leading to the break of both concrete and steel tubbing along the inclined section.

2. Before failure of the test element occurs, the inner steel tubbing has no apparent bending deformation. The failure of the inner and outer steel tubbing and concrete between occurs altogether along the inclined section.

Testing result of the outer steel tubbing of composite shaft lining shaws that compression shearing failure also occurs along the inclined section. The course of failure is: When the loading applied is greater than 70%-80% of the ultimate strenght, the tangential stress of the inner rim of the concrete exceeds R_a^b, then spalling and tiny diagonal cracks occur on the inner side of reinforced concrete. As the loading increases, a small part of the reinforcement is exposed and bends inward. When the loading applied reaches to the ultimate strength, the inclined section broken along the inner side breaks abruptly by shearing.

Similarly, the mode of failure of inner steel tubbing composite shaft lining is also by compression-shearing. The characteristics of the failure is the same as that of the dovble steel tubbing composite shaft lining. Generally, the inner steel tubbing firstly occurs partly longitudinal bending and losing stability, then failure by shearing occurs along the inclined section.

Measured ultimate load of composite shaft lining of concrete and steel tubbings

Load-bearing capacity

An analysis made on the load-bearing capacity of compositing shaft lining of different types of structures (table 1) reveals that:

Table 1

Measured ultimate strenght of composite shaft lining of concrete and steel tubbing

Test Element Number	Type of Structure	Size of Test Element Steel plane (mm) IDxODxH	thickness		S (%)	R 0.1 MPa	DLSL 0.1 MPa
			IT	OT			
SS-83-2	CSCSDT	925x730x562	2.5	2.5		453	300
SS-84-9	CSCSDT	925x730x562	2.0	2.0		477	280
WS-83-7	CSCSOT	925x730x562	0	3.0	0.87	310	170
WS-84-12	CSCSOT	925x730x562	0	3.0	0.87	485	200
NS-83-5	CSCSIT	925x730x562	3.0	0	0.87	314	100
NS-83-6	CSCSIT	925x730x562	3.0	0	0.44	359	125

note: ID - Inner diameter; OD - Outer diameter; H - Height
OT - Outer steel tubbing; IT - Inner steel tubbing;
CSCSDT - Composite shaft lining of concrete and steel double tubbing;
CSDSOT - RC and single steel outer tubbing of composite shaft lining;
CSCSIT - RC and single steel inner tubbing of composite shaft lining;
R - Compressive strenght of concrete; S - Reinforcement ratio;
DLSL - Ultimate strenght of the test element of composite shaft lining.

If the test element of shaft lining is such that its thickness, reinforcement ratio and strength of reinforeed concrete are all the same, the load-bearing capacity of the inner tubbing of the composite shaft lining is much lower than that of the outer tubbing. As the outer steel tubbing of the double steel tubbing composite shaft lining is water-tight, the inner and outer steel tubbings and the concrete together give a good combining action which makes the concrete between being in a state of threedimensional compression, and increase its strength remarkably. If the quantity of the reinforcement used and the grade of concrete for all these three types of composite shaft lining are all of the same, the load-bearing capacity of double steel tubbing composite shaft lining is better than that of the above other two types of composite shaft lining.

Problems of Present Disigning and Calculating Method

As proviously stated, in designing and calculating the composity shaft lining of concrete and steel tubbing, the methods presently used both at home and abroad are H. Link's equation of West Germany and the author's elastic composite tubbing method. Test results have shawn that the actual utlimate strength of composite shaft lining is much greater than the designed value obtained from the present designing and calculating methods especially in the double steel tubbing composite shaft lining. Table 2 shaws that comparing the designed allowable load with the ultimate strength obtained in the tests, the factor of safety is as high as 7.73.

Table 2

Comparision of the load-bearing capacity with the calculated results in the design of composite shaft lining of concrete and steel tubbing

Test Element Number	Type of Structure	Calculated Value by H. Ling method		Ultimate Strenght from Testing 0.1 MPa	Factor of safty	
		maximum allowable 0.1 MPa	utlimate strength 0.1 MPa		SCAD	SCAT
SS-83-2	CSCSDT	38.8	66.0	300	1.7	7.73
SS-84-9	CSCSDT	36.6	62.2	280	1.7	7.65
SS-84-10	CSCSDT	31.9	54.2	180	1.7	5.64
SS-84-11	CSCSDT	27.8	47.3	180	1.7	5.04
NS-83-5	CSCSIT	26.0	44.2	170	1.7	6.54
NS-83-6	CSCSIT	35.7	60.7	200	1.7	5.60

note: SCAD - Factor of safety of allowable load for designing;
SCAT - Factor of safety of allowable load for testing;
CSCSDT and CSCSIT are of the Same meanings as those used in Table 1.

Reasearch result shows that the following problems exist in the present designing methods:

a. The present methods used have not taken into consideration the load-bearing capacity of the structure and the plastic properties of the materials.

b. The present methods used have not taken into consideration the composite shaft lining of concrete and steel tubbing as a kind of composite structure that both steel tubbing and concrete as a whole whould give and excellent composite action which has enhanced the strength of the structure.

c. The strength conditions assumed are not reasonable.

Equations for Calculating Ultimate Load of Composite Shaft Lining of Concrete and Steel Tubbing

1. Half-experience and half-theory equation Based on the results obtained from the structural test of compositing shaft lining of concrete and steel tubbing and by means of analysis for structural plastic limit designing method. Mohr's strength criterion and dimensional analysis, the equations for calculating the ultimate load of composite shaft lining of RC and double steel tubbing are given as follows:

$$P_b = \frac{\sigma_s \cdot A_g + (1+m) \cdot R_a^b \cdot A_h}{r_o} \tag{1}$$

where

$$m = c \cdot \frac{A}{r_1}^{a} \cdot \frac{(\sigma_s)}{R}^{b} \cdot W^b \tag{2}$$

where:

P_b - The ultimate load-bearing capacity of composite shaft lining, MPa;

σ_s - The designed strength of steel, MPa;

A_g - Total thickness of inner and outer steel tubbing, cm;

R_a^b - The standard axial compressive strength of the concrete rhombohedron, MPa;

A_h - Thickness of reinforced concrete, cm;

A - Thickness of shaft lining, cm;

m - Coeficient of increasing strength of the concrete;

r_1 - Internal radius of shaft lining, cm;

r_o - External radius of shaft lining, cm;

R - The strength of RC cube, MPa;

W - Reinforcement ratio;

a,b,c,d - Coefficients of model test.

The increased strength coefficient of RC depends on the diameter of the shaft, the thickness of the shaft lining, the strength of concrete, the thickness and strength of the steel tubbing etc. The values of a,b,c and d are determined by test, substituting these values into Equation (2), the value m is obtained.

2. Theoretical Equation

The theoretical equation for calculating the composite shaft lining of concrete and double steel tubbing is deduced from the theory of elasticity and plasticity:

$$P_{12} = \frac{-KG2 + \sqrt{KG2 - 4 \;.\; KG1 \;.\; KG3}}{2 \;.\; KG1}$$

where $Kg1 = (R_2/H_1)^2$; $KG2 = \frac{R_2}{H_1} \;.\; Z \;.\; h$; $KG3 = Z \;.\; h^2 - \sigma_b^2$

R_1, R_2 - the radio of the inner and outer rims of inner steel tubbing respectively, cm;

h - the shaft depth corresponding to the ultimate load, cm;

Z - Specific gravity of steel tubbing, kg/cm^3.

Table 3

The compresion of the calculated ultimate load with the testing result

Test Element Number	Size of Test Element (mm)			DLT 0.1 MPa	DLEH 0.1 MPa	DLTE 0.1 MPa	η_1 %	η_2 %
	inner diameter	outer diameter	height					
SS-84-16	925	770	562	140	163	145	14.1	4
SS-84-17	925	770	562	180	182	181	1	0.5
SS-85,1	925	770	562	175	160	156	8.6	10.8
SS-85-2	925	737.3	562	110	121	112	10	1.87
SS-84-12	925	770	562	180	191	188	6	4.34
SS-84-15	925	770	562	175	159	169	9.1	3.6
ZG-9	360	295.6	500	150	181	145	20	3.45
ZG-7	360	278.8	500	290	331	256	14	13.41
ZM-3	180	144	225	210	240	215	14	2.3
ZM-6	180	144	225	225	229	215	0.4	6.59

note: DLT - Ultimate strength measured in testing;

DLEH - Ultimate strength Calculated from Equation (1) by half-experience and haft-theory method;

DLTE - Ultimate strength calculated by theoretical Equation (2);

η_1 - Error of DLT with DLEH; η_2 - Error of DLT with DLTE

H_1 - Thickness of the inner steel tubbing, cm;

σ_b - Ultimate strength of steel tubbing, MPa.

$$P_{23} = 1(K-1) \,.\, ((R_3/R)^{K_{c-1}}(P_{12}.(K_c-1) + \sigma_c) - \sigma_c) \tag{4}$$

$$P_b = \frac{KE2 + \sqrt{KE1-4 \,.\, KE1 \,.\, KE3}}{2 \,.\, KE1} \tag{5}$$

In equation (5)

$$KE1 = \left(\frac{R_1}{H_2}\right)^2 ; \quad KE2 = \frac{2 \,.\, R_4^2 \,.\, P_{23}}{H_2^2} + \frac{R_3 zh}{H_2}$$

$$KE3 = Z^2 \,.\, h^3 - \sigma_b^2 + \frac{P_{23} \,.\, R_4 \,.\, z \,.\, h}{H_2} + \frac{R_3^2 \,.\, P_{23}^2}{H_2^2}$$

In equation (4) and (5):

K_c - Effect coefficient of confining pressure;

R_3 R_4 - Radii of inner and outer rims of the outer steel tubbing rescpectively, cm;

H_2 - Thickness of outer steel tubbing, m;

P_{12} . P_{23} - Pressures acting on the concrete between the inner and the outer steel tubbing. MPa;

P_b - Ultimate load, MPa.

The theoretical equation is solved by reiterative method with electronic computer.

Table 3 shows the difference between the calculated value and the measured value is not greater than 20% of the latter.

Conclusions

1. For composite shaft lining od RC and steel tubbing, it has been found that double steel tubbing is better than single steel tubbing in the following respects: Higher loadbearing capacity, smaller tubbing thickness and reinforcement consumption; better ability of bearing uneven, ground pressure and more water-tight. It is a promising shaft lining structure for the deep shaft in the future development of shaft lining structure.

2. Test shows that with the range of elasticity the value of sectional stress of the composite shaft lining of concrete and steel tubbing agrees with that of theoretical analysis for elastic composite tubbing.

3. Composite shaft lining of RC and double steel tubbing gives an excellent combined action, and its RC strength can be increased by 2 ~ 5 times.

4. The failure characteristics of composite shaft lining of concrete and steel tubbing is the piezo-shearing along an inclined section. Therefore, in order to increase the loadbearing capacity of shaft lining, something should be done to increase the shear strength of shaft lining materials.

5. For properly designing the composite shaft lining of concrete and steel tubbing, improvement shold be made in the present designing methods. For this reason, based on the results obtained from this research, the authors have made a further study on the ultimate load designing method so as to seek a more reasonable method for designing the composite shaft lining of concrete and steel tubbing.

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BADANIE WYTRZYMAŁOŚCI MIESZANEJ OBUDOWY SZYBU Z BETONU I STALOWEGO TUBINGU

Streszczenie

W artykule autorzy przedstawiają, na podstawie prób naprężeń i zniszczenia, dwa różne rodzaje obudowy szybu z betonu i tubingu stalowego oraz analizę w stanie obciążenia, jak również mechanizm zniszczenia mieszanej obudowy szybu, aby wykazać, że obudowa szybu złożona z betonu i podwójnego stalowego tubingu dają większą obciążalność wskazując równocześnie na problemy występujące w metodach projektowania obudowy szybowej stosowanych obecnie.

W ostatniej części podają równania dla obliczania obciążenia niszczącego mieszanej obudowy szybu.

ИССЛЕДОВАНИЯ ПРОЧНОСТИ СМЕШАННОЙ ШАХТНОЙ КРЕПИ, ВЫПОЛНЕННОЙ ИЗ БЕТОНА И СТАЛЬНОГО ТЮБИНГА

Резюме

В статье авторы представляют на основе опытов по напряжению и разрушению два различных типа шахтных крепей из бетона и стального тюбинга, а также производят анализ напряжённого состояния и механизм разрушения смешанной шахтной крепи для того, чтобы показать, что шахтная крепь из бетона и стального тюбинга даёт большую нагрузочную способность, указывая одновременно на проблемы применяемых в настоящее время методов проектирования шахтных крепей.

В заключении даны формулы для расчётов разрушающего напряжения смешанной шахтной крепи.