ISBN 978-93-84422-22-6
Proceedings of 2015 International Conference on Innovations in Civil and Structural Engineering (ICICSE 2015)
Istanbul (Turkey), June 3-4, 2015 pp. 213-219

Result Comparison of Resistance under Load Action with Different Appliance Angle in Timber Structures

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Abstract: *In designing timber structures in Albania it is often used beside the Albanian norms STASH*[1]*, even the Eurocode 5*[2]*and the German Code DIN* [3]*. Everyday more the implement of Eurocodes is becoming a challenge for the engineers involved in the design field. Using different design codes, we notice deviation on the estimation of the design parameters of structures. Through this article, comparison of resistance under load action with different appliance angle refereed to fibers, in timber structures, based in standard from STASH, DIN, and EC.5, and identification of differences among them.*

Keywords: *timber, norms, resistance, fibre, appliance angle of loads.*

1. Introduction

The interdependence between axial stress and the orientation of the fibers has often been studied to analyze the orthotropic behavior of timber. However, it is possible to find several examplesin literature that express this relation.

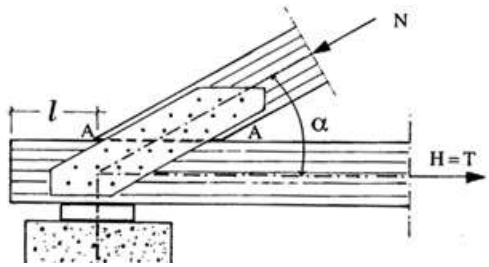

Fig. 1: The applied load at an angle to the grain

This equation takes under consideration stresses in the direction of the anisotropic axis, nominal stresses parallel and perpendicular with fibers, and also tangential stresses. In the following paragraphs are shown the basic expressions which estimate the resistance depending on the direction of the applied load, based on the norms taken under consideration in this article. Hankinson's expression [4]for calculating the resistance depending on the direction of the applied loads is the most famous for its simplicity and applications.

According to the***European codes (EC.5),*** the evaluationof resistance depending on a not specified direction, based on the expression (1.1), proposed by Hankinson is:

$$N = \frac{P*Q}{P*sen^2(\theta)+Q*cos^2(\theta)} \quad [N/mm^2] \qquad (1)$$

Where: N – Resistance value for an applied force angle θ;

P –Resistance value on the direction parallel with the fibers ($\theta=0^0$);

Q –Resistance is the resistance value on the direction perpendicular with the fibers ($\theta=90^0$);

θ –Appliedload angle in relation to the direction of the fibers;

According to the ***Germannormative DIN,*** the evaluationof resistance depending on a not specified direction, it is derived by the following expression:

$$\sigma_{c\theta} = \sigma_{c\eta} - (\sigma_{c\eta} - \sigma_{c1}) * sen(\theta) \quad [N/mm^2] \qquad (2)$$

Where: $\sigma_{c\theta}$ – Maximal allowed stress in direction θ of the applied force.

$\sigma_{c\eta}$ –Maximal allowed stress in the direction parallel with the fibers ($\theta=0^0$);

σ_{c1} –Maximal allowed stress perpendicular with the fibers ($\theta=90^0$);

θ –Applied load angle in relation to the direction of the fibers;

According to the ***Albanian standard STASH*** the resistance in a not specified direction, is given by the expression (1.3), written below:

$$R^{\alpha}_{ngj,ter} = \frac{R_{ngj,ter}}{1 + (\frac{R_{ngj,ter}}{R^{90°}_{ngj,ter}} - 1) * \sin^3 \alpha} \quad [N/mm^2] \qquad (3)$$

Where: $R^{\alpha}_{ngj,ter}$ – Resistance value for an applied force angle θ;

$R_{ngj,ter}$ – Resistance value on the direction parallel with the fibers ($\theta=0^0$);

$R^{90°}_{ngj,ter}$ – Resistance is the resistance value on the direction perpendicular with the fibers ($\theta=90^0$);

2. Aim of the Study

When the applied load has an inclination θ after the direction of the fibres, like in lateral brace of a truss above the bottom chord, it is necessary to determine the resistance after the direction of the applied load.

The aim of this study it is to compare the resistance after the direction of inclined load, with angle θ, with the direction of the fibres and the identification of the differences from these conclusions.

In this study, have been taken under account references from the Eurocode 5, the German Standard DIN and the Albanian one STASH

3. Classification of Timber Elements.

Classification of timber elements used in structures it is based on its strength class. According to European codes [5], classification of timber is divided in two categories. C Category, for coniferous trees and poplar trees, D category for broafleaf trees. Timber from category C are the important ones and most used in Europe, even though in recent years tropical have been used even timber from trees of category D (such as beech and oak). This study has been conducted using timber from class C16, for its spreading.

Table I:Strength classes and characteristic valuesof timber, Category C [5]

		C14	**C16**	C18	C20	C22	C24	C27	C30	C35	C40	C45	C50
Strength properties (N/mm^2)													
Bending	$f_{m,k}$	14	16	18	20	22	24	27	30	35	40	45	50
Tension parallel	$\mathbf{f_{t,0,k}}$	8	**10**	11	12	13	14	16	18	21	24	27	30
Tension perpendicular	$\mathbf{f_{t,90,k}}$	0,4	**0,5**	0,5	0,5	0,5	0,5	0,6	0,6	0,6	0,6	0,6	0,6
Compression parallel	$\mathbf{f_{c,0,k}}$	16	**17**	18	19	20	21	22	23	25	26	27	29
Compression perpendicular	$\mathbf{f_{c,90,k}}$	2,0	**2,2**	2,2	2,3	2,4	2,5	2,6	2,7	2,8	2,9	3,1	3,2

4. Analyzing the Numerical Data

Taken under consideration the above mentioned expressions for tension and compression strength in the same direction as the applied force, calculations have been made depending on the angle of the applied load.This

calculation considers the applied forces, in tension or compression, with appliance angle varying from zero to ninety degree with a fifteen degree pace.

4.1 Numerical Analysis Based on the European Code EC.5

Referring to the analytic expression (1) from Hankinson, according to the European code (EC5) for timber characteristics C16, the results taken from the numerical analysis are presented in the table below.

TABLE II:Strength values in tension and compressions for class C16timber depending on the appliance angle of the load action (according to EC.5).

Applied load angle(degree)	Hankinson formula $N = \frac{P*Q}{P*sen^2(\theta)+Q*cos^2(\theta)}$ $[N/mm^2]$			
	Tension (N/mm^2)		Compression (N/mm^2)	
	P=10 N/mm^2; Q=0,5 N/mm^2		P=17 N/mm^2; Q=2,2 N/mm^2	
	N	N/P	N	N/P
0,0	10,00	1,00	17,00	1,00
15,0	4,40	0,44	11,72	0,69
30,0	1,74	0,17	6,34	0,37
45,0	0,95	0,10	3,90	0,23
60,0	0,66	0,07	2,81	0,17
75,0	0,53	0,05	2,34	0,14
90,0	0,50	0,05	2,20	0,13

The interrelation between the strength N (N/mm^2)indirection of the applied load angle with the strength P (N/mm^2) in the direction parallel with the fibres, it is presented in the graphic below:

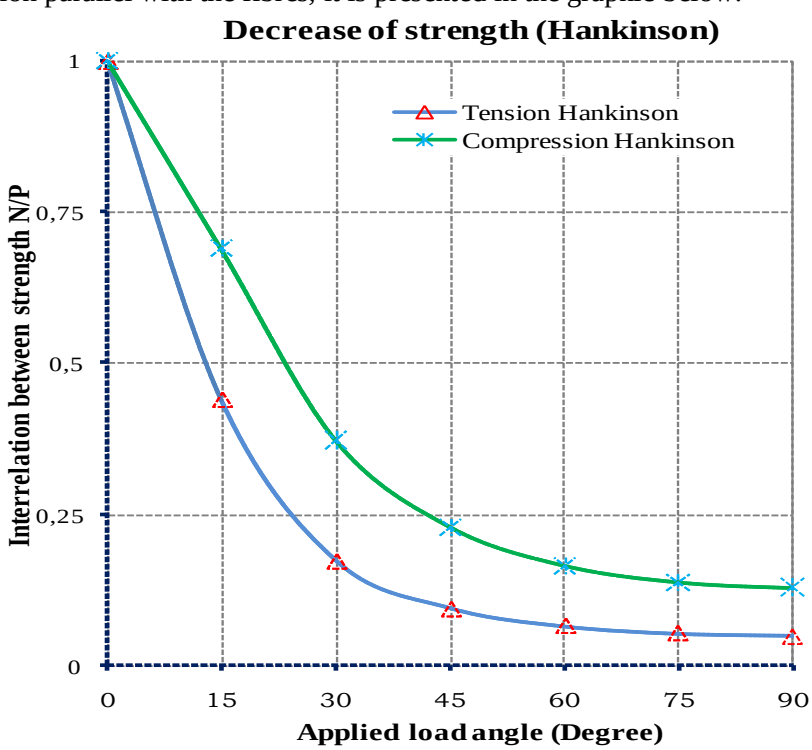

Fig. 2: The diagram between the strength in tension and compression for an applied load angle θ (according to EC.5)

4.2 Numerical Analysis Based on the German Code DIN

Referring to the analytic expression (2), according to the German code (DIN) for class C16 timber characteristic, the results from the analytic calculation are presented in the table below.

TABLE III:Strength values in tension and compressions for class C16 timber depending on the appliance angle of the load action(according toDIN).

Applied load angle (degree)	DIN – German Code $\sigma_{c\theta} = \sigma_{c\eta} - (\sigma_{c\eta} - \sigma_{c1}) * sen(\theta)$ [N / mm²]			
	Tension (N/mm²)		Compression (N/mm²)	
	$\sigma_{c\eta}$ =10 N/mm²; σ_{c1} =0,5 N/mm²		$\sigma_{c\eta}$ =17 N/mm²; σ_{c1} =2,2 N/mm²	
	$\sigma_{c\theta}$	$\sigma_{c\theta} / \sigma_{c\eta}$	$\sigma_{c\theta}$	$\sigma_{c\theta} / \sigma_{c\eta}$
0,0	10,00	1,00	17,00	1,00
15,0	7,54	0,75	13,17	0,77
30,0	5,25	0,53	9,60	0,56
45,0	3,28	0,33	6,54	0,38
60,0	1,77	0,18	4,18	0,25
75,0	0,82	0,08	2,70	0,16
90,0	0,50	0,05	2,20	0,13

For this case the interrelation between the strength $\sigma_{c\theta}$ (N/mm²) in the direction of the applied load with the resistance $\sigma_{c\eta}$ (N/mm²) in the direction parallel with the fibres, it is presented in the graphic below:

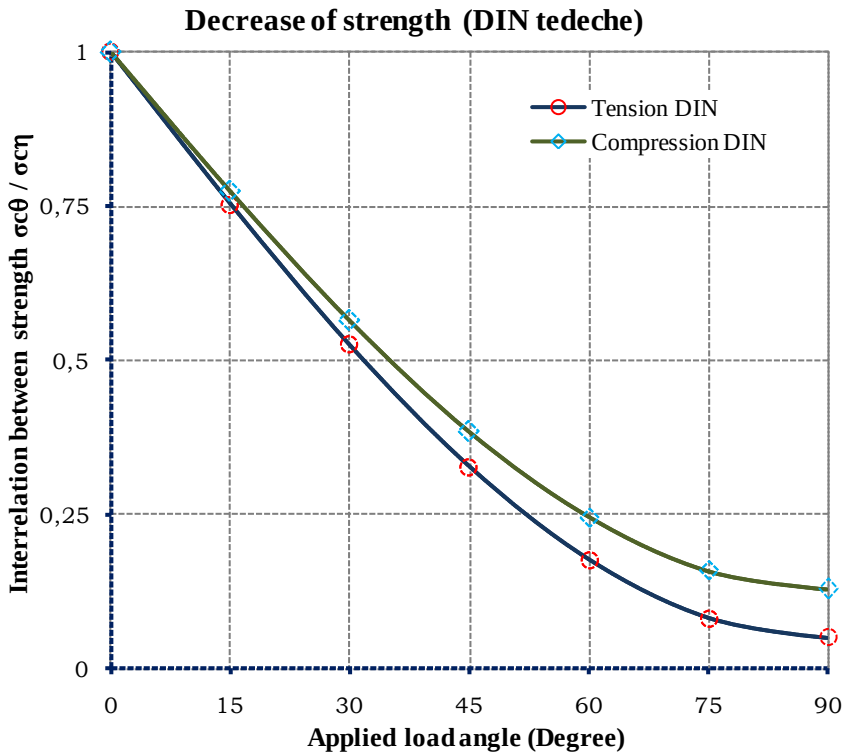

Fig.3: The diagram between the strength in tension and compression for an applied load angle θ (according toDIN).

4.3 Numerical Analysis Based on the Albanian Code STASH

Referring to the analytic expression (1.3), according to the Albanian code (STASH) for class C16 timber characteristic, the results from the analytic calculation are presented in the table below:

TABLE IV:Strength values in tension and compressions for class C16timber depending on the appliance angle of the load action (according toSTASH).

Applied load angle (degree)	STASH – Albanian code $R^{\alpha}_{ngj,ter} = \frac{R_{ngj,ter}}{1+(\frac{R_{ngj,ter}}{R^{90°}_{ngj,ter}}-1)*\sin^3\alpha}$ [N / mm²]			
	Tension (N/mm²)		Compression (N/mm²)	
	R_{ter} =10 N/mm²; $R^{90°}_{ter}$ =0,5 N/mm²		R_{ngj} =17 N/mm²; $R^{90°}_{ngj}$ =2,2 N/mm²	
	R^{α}_{ter}	$R^{\alpha}_{ter} / R_{ter}$	R^{α}_{ngj}	$R^{\alpha}_{ngj} / R_{ngj}$
0,0	10,00	1,00	17,00	1,00
15,0	7,52	0,75	15,22	0,90
30,0	2,96	0,30	9,23	0,54
45,0	1,30	0,13	5,03	0,30
60,0	0,75	0,07	3,17	0,19
75,0	0,55	0,06	2,41	0,14
90,0	0,50	0,05	2,20	0,13

For this case the interrelation between the strength $R^{\alpha}_{ngj,ter}$ (N/mm²) in the direction of the applied load with the resistance $R_{ngj,ter}$ (N/mm²) in the direction parallel with the fibres, it is presented in the graphic below:

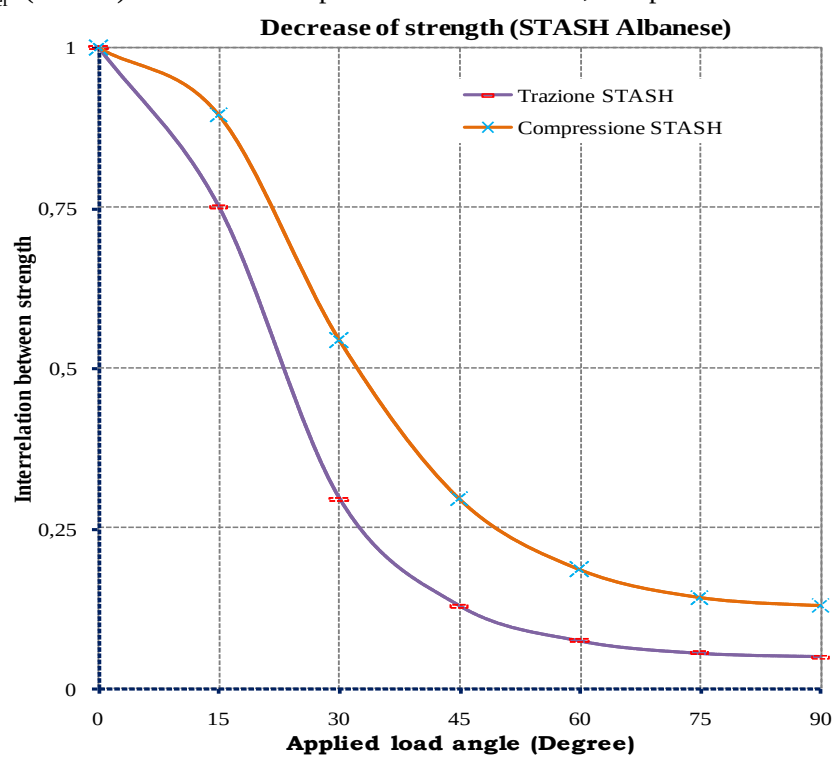

Fig.4: The diagram between the strength in tension and compression for a applied load angle θ (according toSTASH)

5. Numericaland GraphicResult Comparison

Duke u mbeshtetur ne llogaritjet analitike te kryera me siper ne menyre te permbledhur rezultat e perftuara paraqiten ne tabelen e meposhtme.The table below shows, in a summarised way, the results obtained by the analytic calculations above.

TABLE V:Comparison of strength values in tension and compressions for class C16 timber depending on the appliance angle of the load action, according to EC.5. DIN, STASH

Angle (degree)	EC. 5				DIN				STASH			
	$N = \frac{P*Q}{P*sen^2(\theta)+Q*cos^2(\theta)}$ [N / mm²]				$\sigma_{c\theta} = \sigma_{c\eta} - (\sigma_{c\eta} - \sigma_{c1})*sen(\theta)$ [N / mm²]				$R^{\alpha}_{ngj,ter} = \frac{R_{ngj,ter}}{1+(\frac{R_{ngj,ter}}{R^{90°}_{ngj,ter}}-1)*sin^3\alpha}$ [N / mm²]			
	Tension (N/mm²)		Compression (N/mm²)		Tension (N/mm²)		Compression (N/mm²)		Tension (N/mm²)		Compression (N/mm²)	
	P=10N/mm² Q=0,5N/mm²		P=17 N/mm² Q=2,2 N/mm²		$\sigma_{c\eta}$ =10N/mm2 σ_{c1} =0,5N/mm2		$\sigma_{c\eta}$ =17N/mm2 σ_{c1} =2,2N/mm2		R_{ter} =10N/mm2 $R^{90°}_{ter}$ =0,5N/mm2		R_{ngj} =17N/mm2 $R^{90°}_{ngj}$ =2,2N/mm2	
	N	N/P	N	N/P	$\sigma_{c\theta}$	$\frac{\sigma_{c\theta}}{\sigma_{c\eta}}$	$\sigma_{c\theta}$	$\frac{\sigma_{c\theta}}{\sigma_{c\eta}}$	R^{α}_{ter}	$\frac{R^{\alpha}_{ter}}{R_{ter}}$	R^{α}_{ngj}	$\frac{R^{\alpha}_{ngj}}{R_{ngj}}$
0,0	10,00	1,00	17,00	1,00	10,00	1,00	17,00	1,00	10,00	1,00	17,00	1,00
15,0	4,40	0,44	11,72	0,69	7,54	0,75	13,17	0,77	7,52	0,75	15,22	0,90
30,0	1,74	0,17	6,34	0,37	5,25	0,53	9,60	0,56	2,96	0,30	9,23	0,54
45,0	0,95	0,10	3,90	0,23	3,28	0,33	6,54	0,38	1,30	0,13	5,03	0,30
60,0	0,66	0,07	2,81	0,17	1,77	0,18	4,18	0,25	0,75	0,07	3,17	0,19
75,0	0,53	0,05	2,34	0,14	0,82	0,08	2,70	0,16	0,55	0,06	2,41	0,14
90,0	0,50	0,05	2,20	0,13	0,50	0,05	2,20	0,13	0,50	0,05	2,20	0,13

The graphic below shows summarised for the three standards the interrelation between the tension anda compression strength in the direction of the applied load with the tension strength in the direction parallel with the fibres:

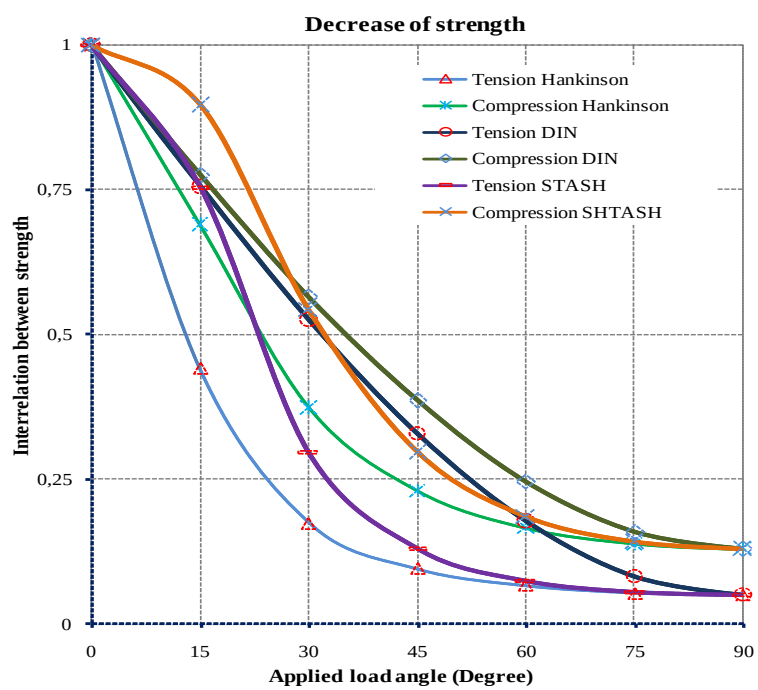

Fig.5: The diagram between the strength in tension and compression for a applied load angle θ (according toEC.5, DIN, STASH).

Ina summarised way, the graphic below shows for the three standards the comparison between the tension and compression strength in the direction of the applied load with the tension and compression strength in the direction parallel with the fibres:

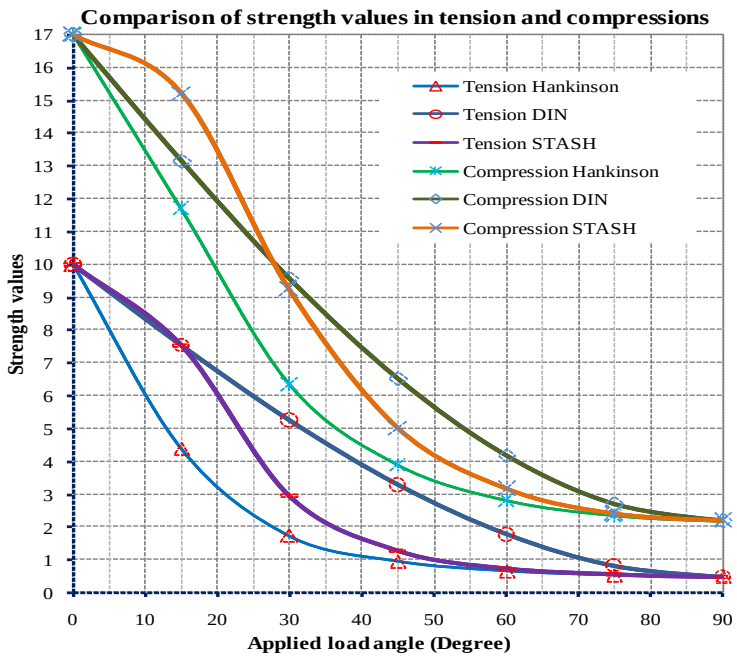

Fig.6: The diagram between the strength in tension and compression for a applied load angle θ(according toEC.5, DIN, STASH).

6. Conclusions

Comparing the obtained results from the calculations referring to the strength in the direction of the applied load angle, or the interrelation between the strength in the direction of the applied load with the strength in the direction parallel with the fibres, both in tension and compression, the below conclusions have been made:

1. The strength values in tension in the direction of the appliedload angle, for an angle $\theta=(0\div15)^0$has similar values with DIN and STASH, and smaller values are obtained using EC.5.
2. The strength values in tension in the direction of the applied load angle, for an angle $\theta=(15\div65)^0$ using EC.5 are still smaller than values using STASH, but both have smaller strength compared to the results obtained using the DIN code.
3. The strength values in tension in the direction of the applied load angle, for an angle $\theta=(65\div90)^0$are similar with EC.5 and STASH, but smaller strength compared to the results obtained using the DIN code.
4. The strength values in compression in the direction of the applied load, for an angle $\theta=(0\div27)^0$ using the EC.5 are smaller than the values obtain with DIN code, and both give smaller values than the ones according to STASH. For an applied load angle $\theta=27^0$the values obtained from DIN code are the same as the strength values obtained using STASH code.
5. The strength values in compression in the direction of the applied load, for an angle $\theta=(27\div73)^0$are still smaller using EC.5 than the ones obtained with STASH, but both give smaller strengths than the one according to DIN code.
6. The strength values in compression in the direction of the applied load, for an angle $\theta=(73\div90)^0$ are similar in when using EC.5 and STASH but both are smaller than the strength values obtained using the DIN code.

7. References

[1] STASH, KTP 10-78 KushtetTekniketeProjektimitteKonstruksioneveprejÇeliku - Tirane 1978.

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