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THTEE-DIMENSIONAL STRESS AND DISPLACEMENT ANALYSIS OF YUTIAO CONCRETE FACED ROCKFILL DAM

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This is a challenging topic

The objective of this study

- Indoor tests and site surveys indicate that there is a great deal of mudstone at the site of Yutiao concrete-faced rockfill dam. Its average compression strength is 18.8MPa and its permeability coefficient is $3.65 \times 10^{-2} cm/s$. It has high degree of weathering and high content of fine particle.
- Whether this soft rock which can be used for the dam is an important problem. If stacking area far away from the dam is adopted, progress of works will be delayed and the investment will increase.
- The left abutmet and the right one are asymmetric. The dip and the inclination are not equal. The effect of three-dimensional characteristics of canyon shape may be obvious.
- During engineering construction, if the gravel content or the grain is low ?

main analysis procedures

- three-dimensional finite element discretization
- Model choice and model parameters
- Finite element analysis method
- Results comparison
- Some conclusions

Finite element mesh

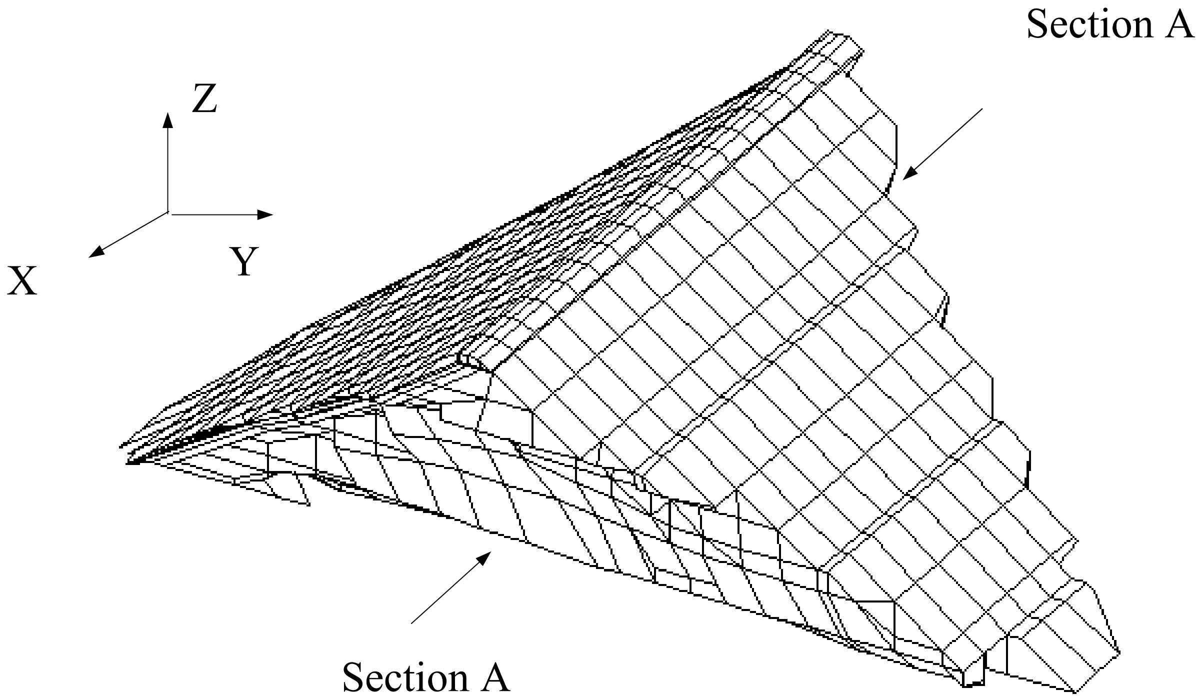


Fig. 1 The three-dimensional finite element discretization of Yutiao dam

Finite element mesh

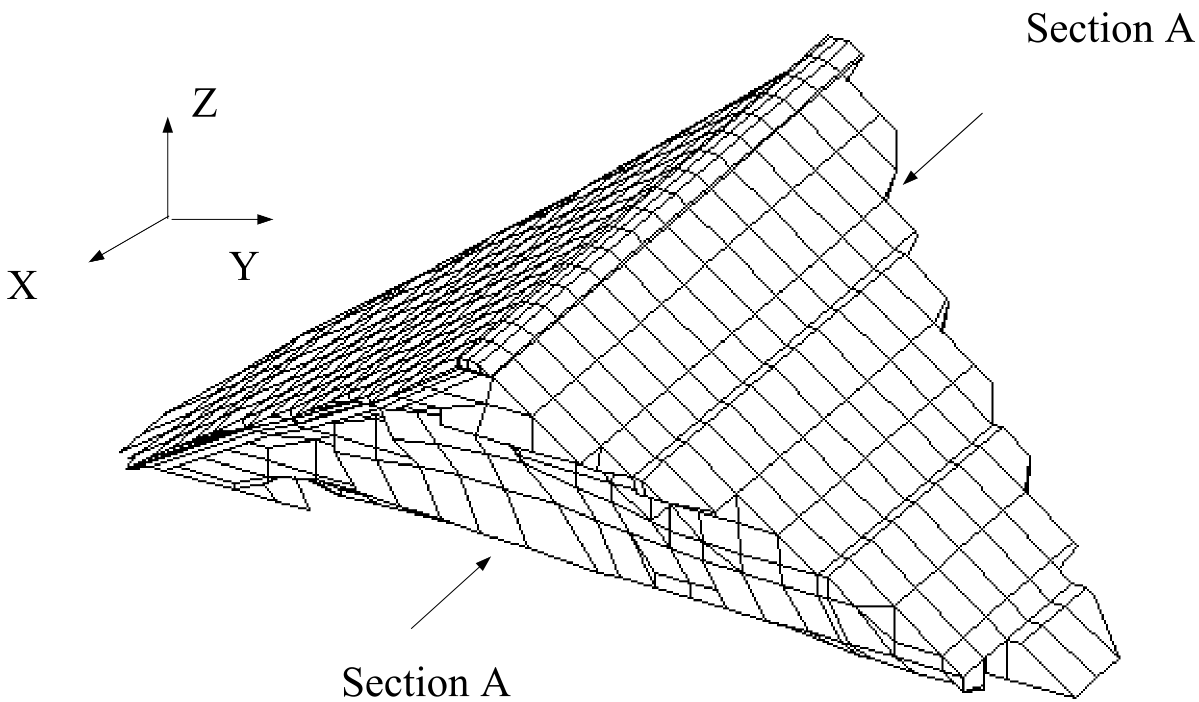
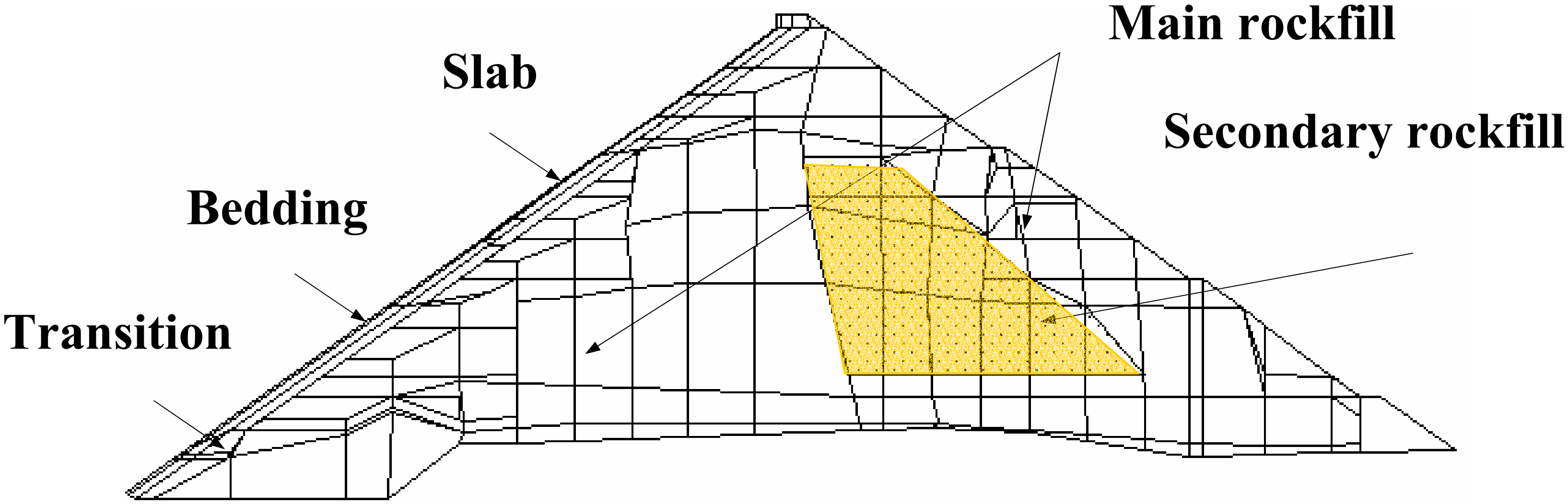


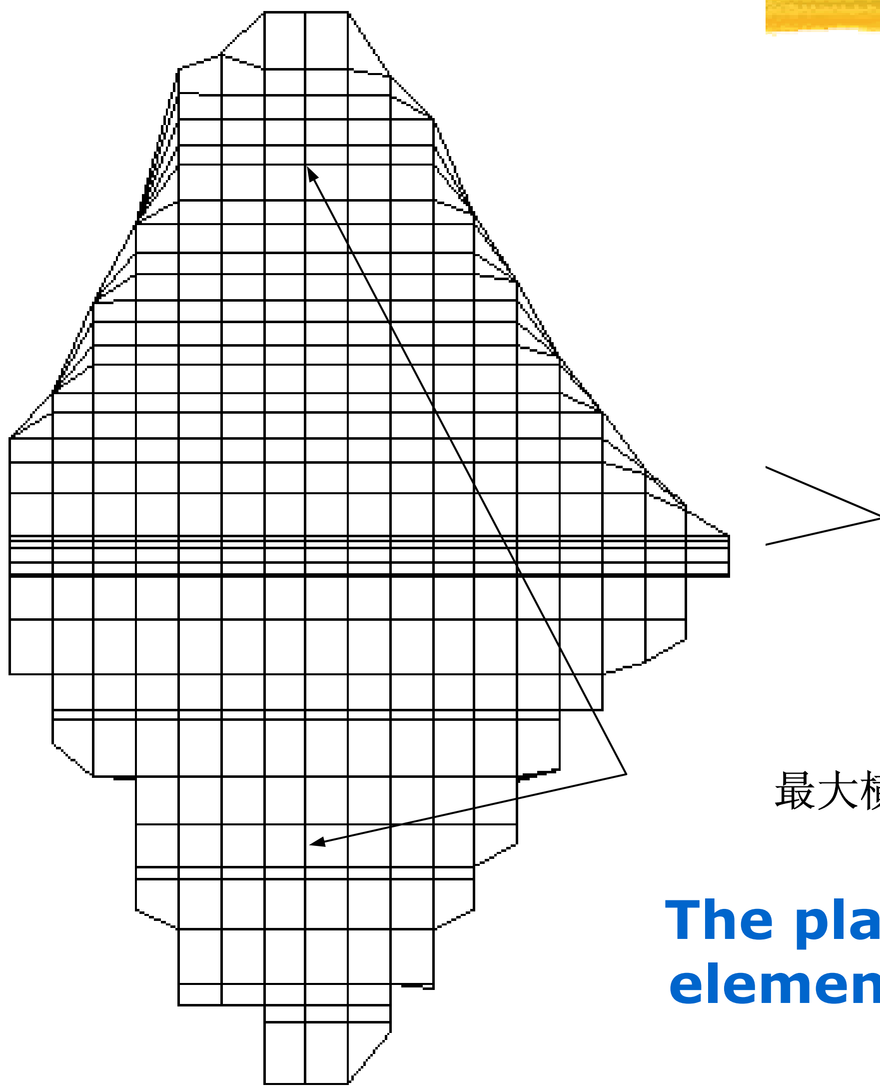
Fig. 1 The three-dimensional finite element discretization of the dam

Finite element mesh



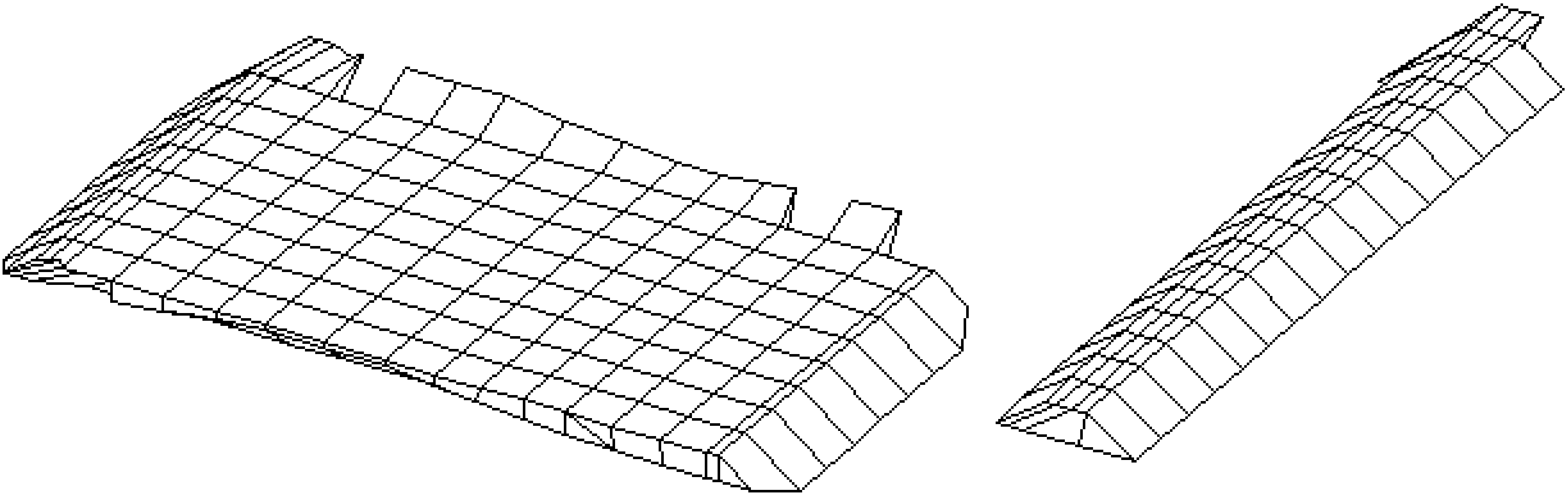
Maximum cross section of the dam

Finite element mesh



The plan-view of finite element discretization

Load steps



The element mesh of five and twele load step

The incremental elastic and hyperbolic Duncan model

- E-B model proposed by Duncan Chang in 1980

tangent modulus of elasticity

$$E_t = E_i \left(1 - R_f \frac{(\sigma_1 - \sigma_3)(1 - \sin\phi)}{2(c\cos\phi + \sigma_3 \sin\phi)} \right)^2$$

$$\phi = \phi_0 - \Delta\phi \log\left(\sigma_3 / p_a \right)$$

unloading modulus of elasticity

$$E_{ur} = K_{eur} p_a \left(\sigma_3 / p_a \right)^n$$

tangent modulus of volume

$$B_t = K_b p_a \left(\sigma_3 / p_a \right)^m$$

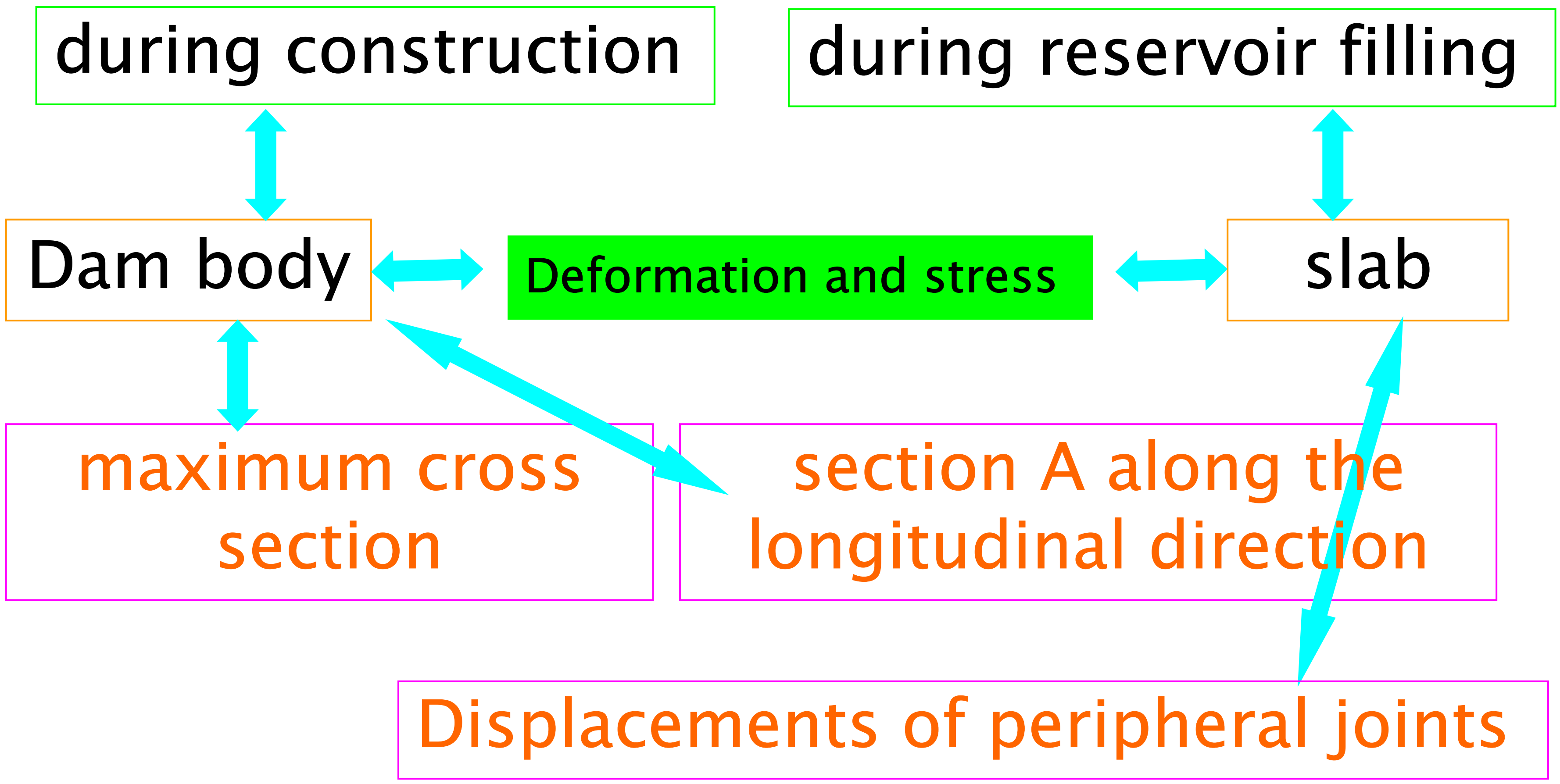
Model parameters of Duncan model

Type	K_e	ϕ_0	$\Delta\phi$	n	R_f	K_b	m
Slab	190000	190000	190000	190000	190000	120000	0
Main rockfill	800	46	0	0.34	0.75	400	0.40
Bedding	910	45	0	0.37	0.65	455	0.40
Transition	850	46	0	0.37	0.65	425	0.48
Secondary rockfill	300	42	5.7	0.17	0.82	166	0.28

midpoint incremental method non-liner deformation characteristics

- In this method, approximate nonlinear solutions can be obtained by a series of linear analyses provided the updated stiffness and damping are compatible with current effective shear strain amplitudes.
- The equivalent effective strain is estimated as a fraction (i.e., 0.65) of peak shear strain in order to define modulus and damping ratio for each iteration from the experimentally-achieved curves.
- Successive iterations are required until compatible dynamic parameters with strain level are acquired.
- Rayleigh's concept of proportional damping is used to represent hysteric damping of soil
- Wilson-θ's numerical integration scheme is combined with equivalent linearization procedure to solve the dynamic equations of the system step-by-step in time domain.

comparative aspects



Deformation and stress of the maximum cross section during construction

Unit: m

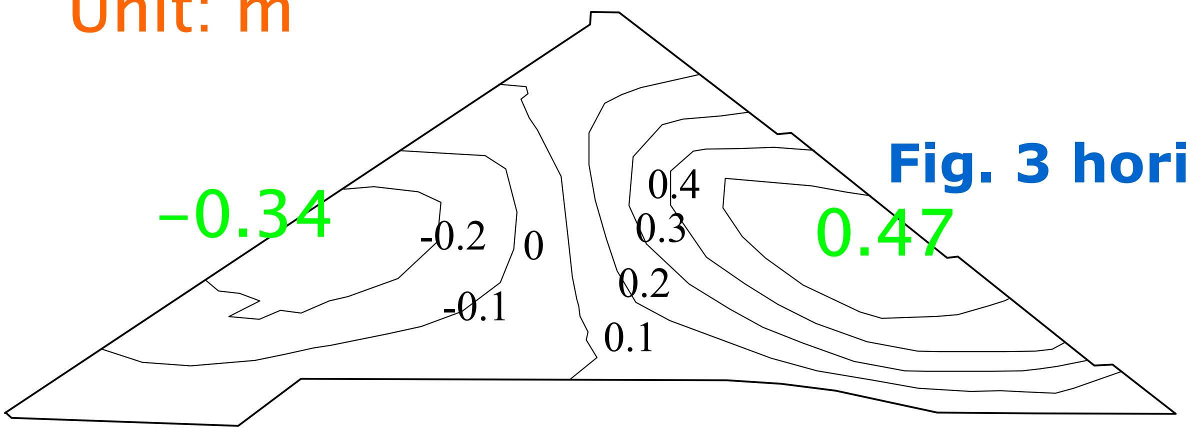


Fig. 3 horizontal displacements

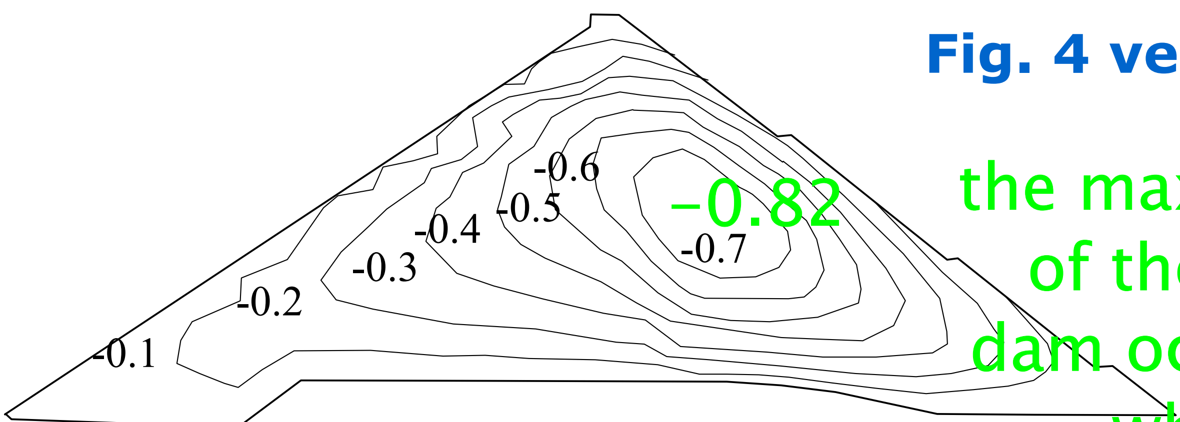


Fig. 4 vertical displacements

the maximum settlement of the homogeneous dam occurs in axial line, which is 0.61m

Deformation and stress of the maximum cross section during construction

Unit: MPa

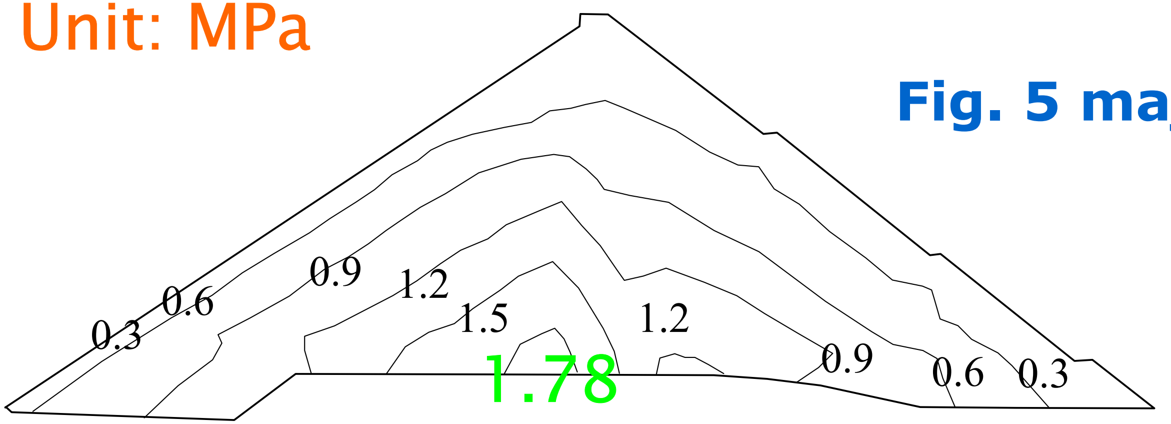


Fig. 5 major principal stresses

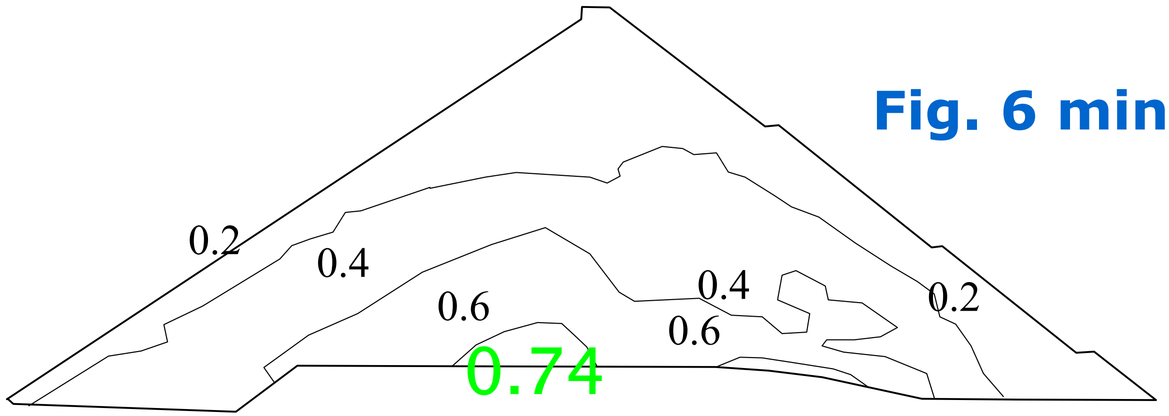


Fig. 6 minor principal stresses

Deformation of section A along the longitudinal direction during construction

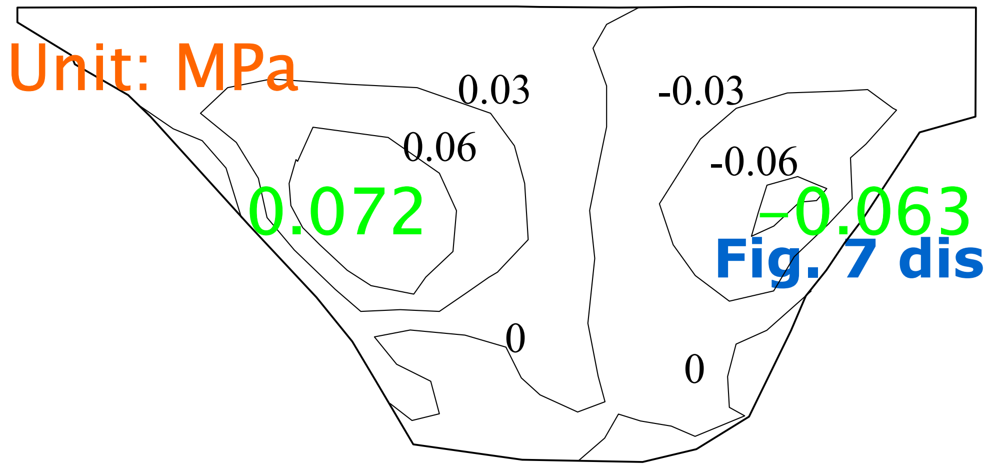


Fig. 7 displacements in X direction

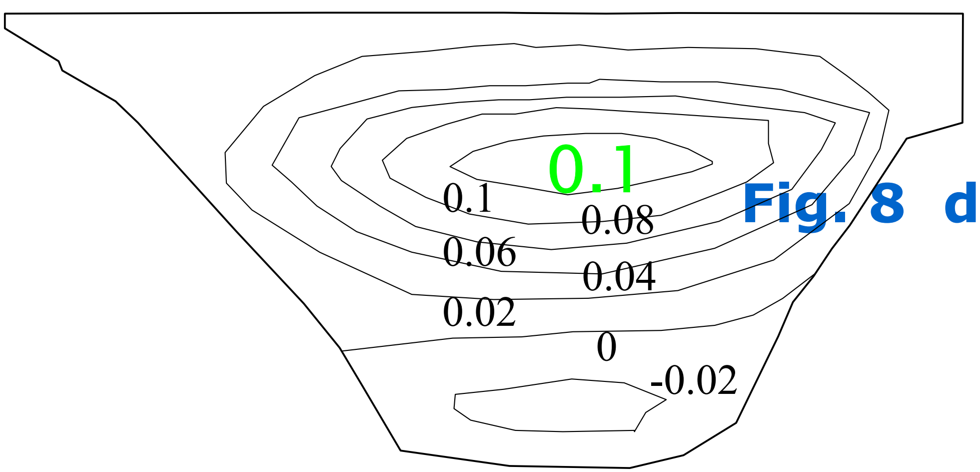


Fig. 8 displacements in Y direction

Stresses and deformations of major cross section during reservoir filling

Unit: m

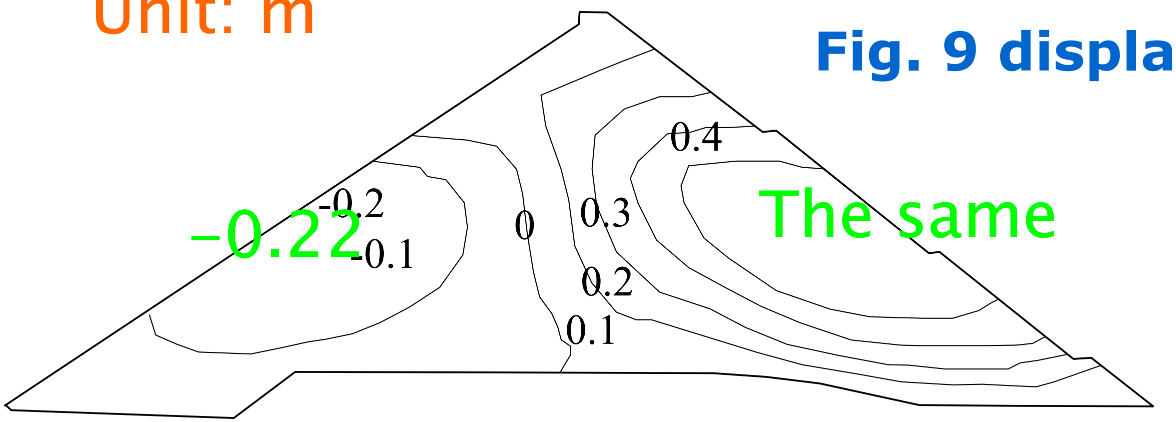


Fig. 9 displacements in y direction

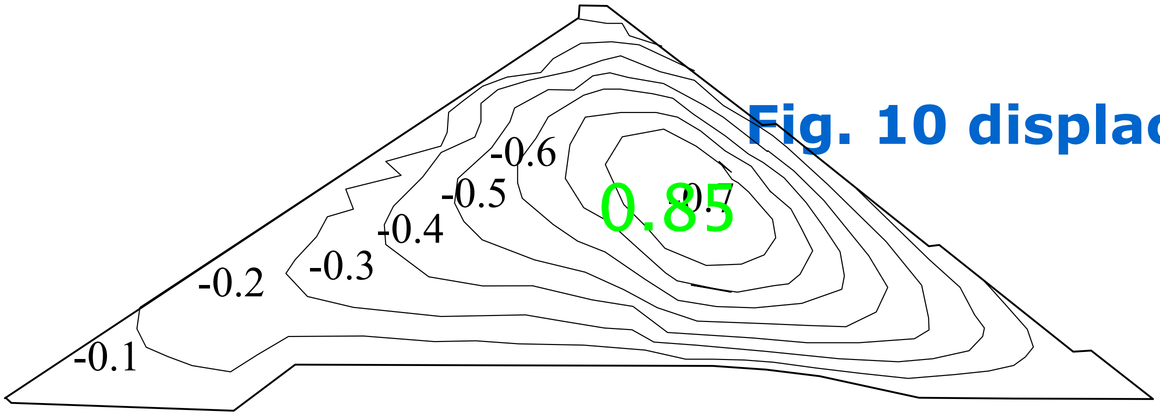


Fig. 10 displacements in Z direction

Stresses and deformations of major cross section during reservoir filling

Unit: MPa

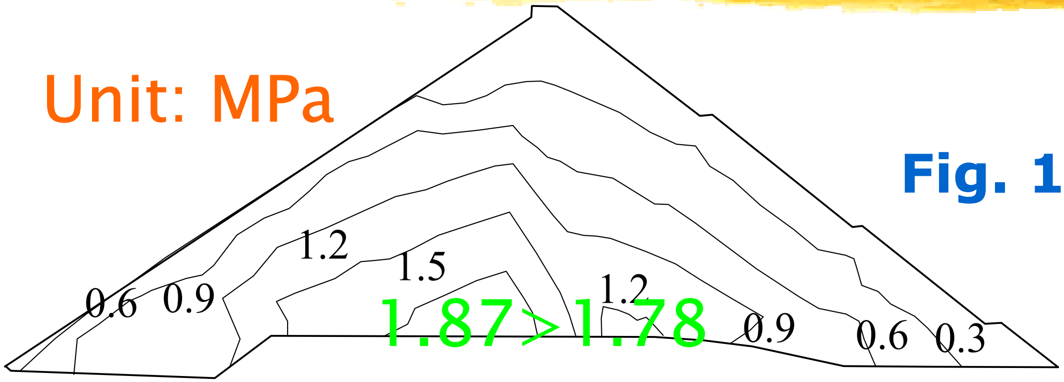


Fig. 11 major principal stresses

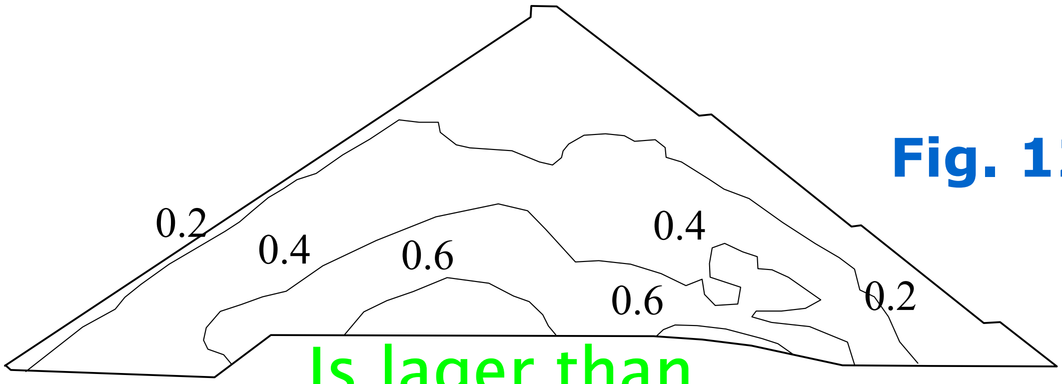
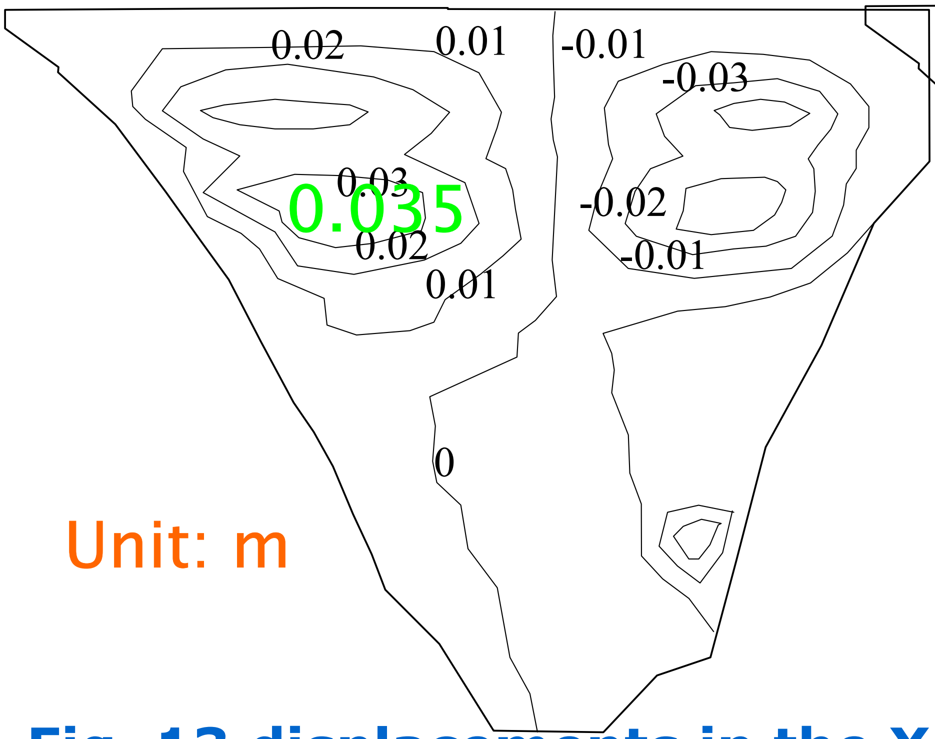


Fig. 12 minor principal stresses

Stresses and deformations of slab during reservoir filling



Unit: m

Fig. 13 displacements in the X direction

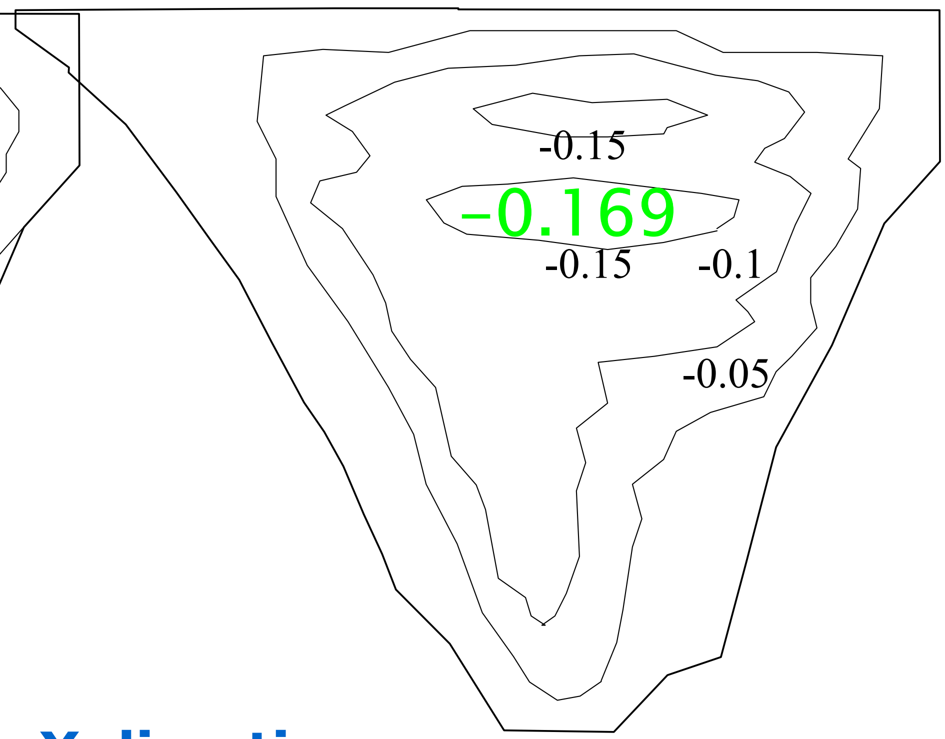


Fig. 14 Contours of displacements in the Z direction

Stresses and deformations of slab during reservoir filling

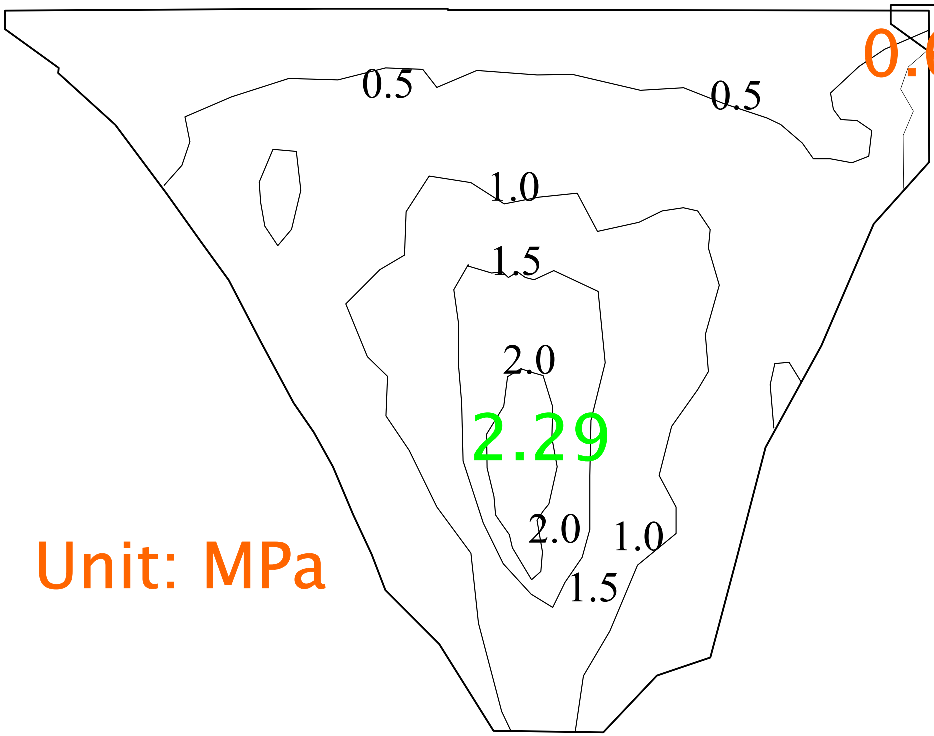


Fig.15 stresses on slab in the direction along the dam slope

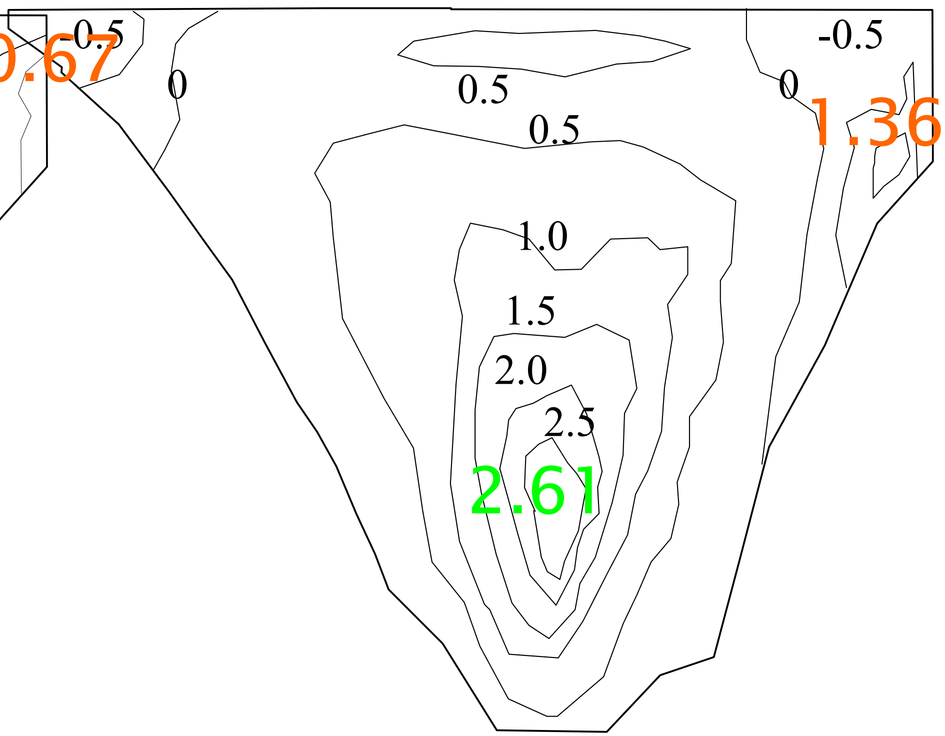
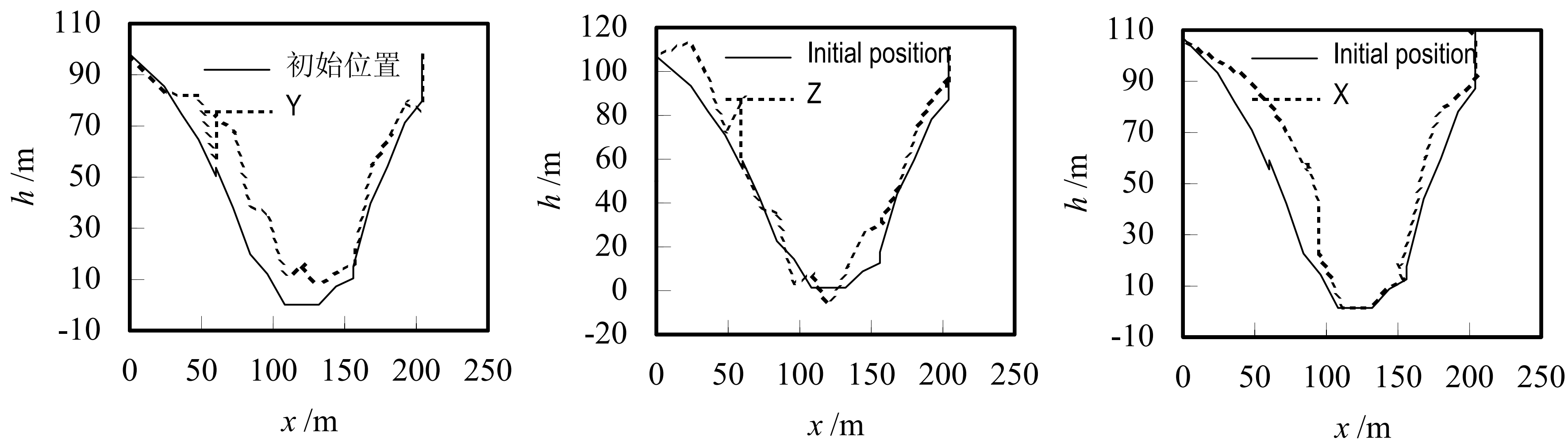


Fig. 16 along the dam axial

Displacements of peripheral joints during reservoir filling



Maximum displacement in X direction occurs at the left bank whose value is 1.06cm and major displacement in X direction of the right bank is –0.59cm. Major displacement in Y and Z direction are 1.46cm and 1.31cm, respectively.

Sensibility analysis of model parameters ---case A

表2 方案A的坝体和面板的应力、位移的最大值

项目			坐标 X	坐标 Y	坐标 Z	计算值
面板	沉降(m)		156	53.87	38.96	-0.188
面板	大主应力		72	74.12	54	309.13
面板	小主应力		108	108.08	78.16	48.17
面板	沿坝轴向应力		156	172.38	87.12	261.2
面板	沿坝坡向应力		120	143.64	87.12	254.36
周边缝位移	X向(mm)	正	60	76.36	55.60	10.62
周边缝位移	X向(mm)	负	192	108.07	78.16	5.86
周边缝位移	Y向(mm)		96	18.45	14.40	14.63
周边缝位移	Z向(mm)		60	76.36	55.60	13.13
坝体	竣工期	垂直位移	120	183.98	59.16	-0.82
坝体	竣工期	水平位移(上游)	156	60.90	38.97	-0.34
坝体	竣工期	水平位移(下游)	120	206.14	50.02	0.47
坝体	竣工期	大主应力	78	167.5	23.89	197.87
坝体	竣工期	小主应力	78	167.5	23.89	74.41
坝体	蓄水期	垂直位移	120	183.98	59.16	-0.85
坝体	蓄水期	水平位移(上游)	156	60.90	38.97	-0.22
坝体	蓄水期	水平位移(下游)	120	206.14	50.02	0.52
坝体	蓄水期	大主应力	78	167.5	23.89	208.18
坝体	蓄水期	小主应力	78	167.5	23.89	77.3

Sensibility analysis of model parameters ---case B

表2 方案A的坝体和面板的应力、位移的最大值

项 目			坐 标			计算值
			X	Y	Z	
面板	沉降(m)		156.00	53.87	38.96	-0.1428
	大主应力		72	74.12	54	256.33
	小主应力		132	89.16	59.13	110.86
	沿坝轴向应力		24	138.18	94.18	1843.1
	沿坝坡向应力		120	143.64	87.12	210.95
周边缝位移	X向(mm)	正	60	76.36	55.60	8.84
		负	192	108.07	78.16	6.11
	Y向(mm)		72	57.52	42.19	18.13
	Z向(mm)		60	76.36	55.60	12
坝体	竣工期	垂直位移	120	183.98	59.16	-0.67
		水平位移(上游)	156	56.88	38.97	-0.27
		水平位移(下游)	120	206.14	50.02	0.39
		大主应力	78	167.5	23.89	198.04
		小主应力	78	167.5	23.89	73.04
	蓄水期	垂直位移	120	183.98	59.16	-0.69
		水平位移(上游)	156	56.88	38.97	-0.26
		水平位移(下游)	120	206.14	50.02	0.42
		大主应力	78	167.5	23.89	208.42
		小主应力	78	167.5	23.89	76.38

Sensibility analysis of model parameters ---case C

项目			坐标			计算值
			X	Y	Z	
面板	沉降(m)		156.00	53.87	38.96	-0.2079
	大主应力		72	74.12	54	348.54
	小主应力		132	89.16	59.13	121.66
	沿坝轴向应力		24	138.18	94.18	322.84
	沿坝坡向应力		120	143.64	87.12	241.94
周边缝位移	X向(mm)	正	60	76.36	55.60	13.06
		负	192	108.07	78.16	5.74
	Y向(mm)		96	18.45	14.40	17.86
	Z向(mm)		60	76.36	55.60	15.89
坝体	竣工期	垂直位移	120	183.98	59.16	-1.05
		水平位移(上游)	156	60.90	38.97	-0.41
		水平位移(下游)	120	206.14	50.02	0.61
		大主应力	78	167.5	23.89	196.81
		小主应力	78	167.5	23.89	75.0
	蓄水期	垂直位移	120	183.98	59.16	-1.09
		水平位移(上游)	156	60.90	38.97	-0.41
		水平位移(下游)	120	206.14	50.02	0.66
		大主应力	78	167.5	23.89	209.82
		小主应力	78	167.5	23.89	78.34

Some Conclusions

- **1) Settlement of the dam is as much as 1% of the dam height, which occurs in the middle of the dam. The major settlement is near downstream slope slightly.**
- **2) The existing of soft rock has not important impact on safety of the dam body and the facing slab. So the current design scheme is approximately feasible and most rockfill can be used. But monitoring of displacements of the dam during construction must be strengthened.**

Some Conclusions

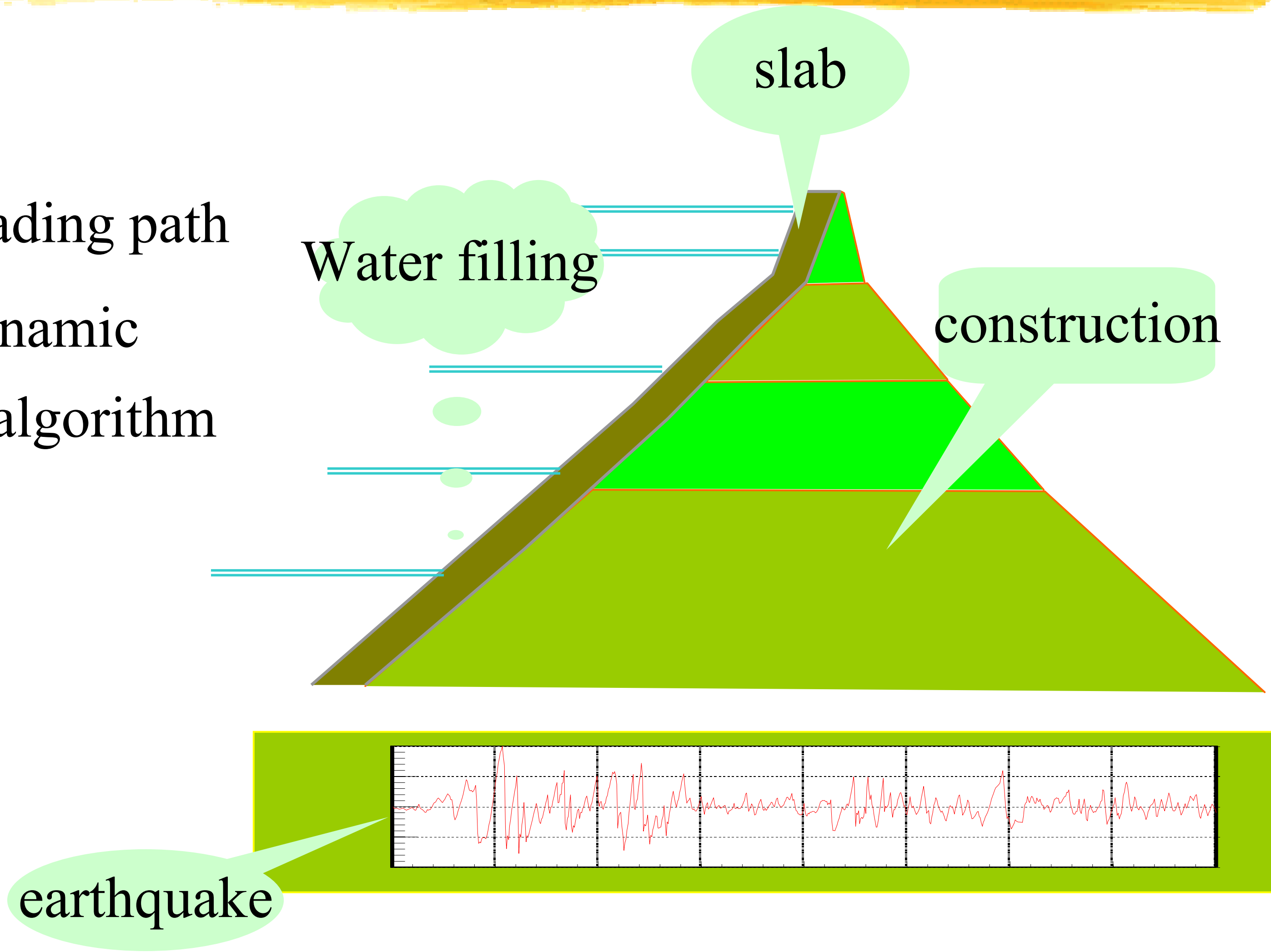
- **3) The displacement of peripheral joints between slab and footwall is small with maximum absolute value of 2cm during reservoir filling, thus some special measures need not to be taken, but the choice of the type of watertight and joint sealing material should be considerate carefully.**
- **4) A few bearing reinforcements need to be set because tension stresses occur in some region of slab.**

Hypoplasticity Bounding Surface model of rockfill materials and static-dynamic incrementally-iterative algorithm for CFRD

Complex loading path

static dynamic

Model and algorithm



Acknowledgements

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