Съгласен
/Нина Пенкова/

До доц. д-р инж. Нина Пенкова
Ръководител на проект:
BG051PO001-3.3.06-0014:
“Център по математично моделиране и компютърна симулация за подготовка и развитие на млади изследователи”

ДОКЛАД
от

Николай Методиев Николов
/име, фамилия/
участник в целевата група по проекта

Уважаема г-жо Ръководител,

Бих желал да бъда информиран за възможността да бъде финансирано в общ размер от 22.56 лв. (двадесет и два лева и 56 ст.) доставянето на следните две научни статии :

Title: Cascade rubber dams fall discharge calculation and analysis,
AUTHOR(S): Zhang, Qinghua; Diao, Yanfang,
PUB. DATE: August 2011,
SOURCE: Canadian Journal of Civil Engineering; Aug2011, Vol. 38 Issue 8,p957;
Title: Dynamic analysis of an inflatable dam subjected to a flood,
Authors: Lowery, K.; Liapis, S.,
Publication: Computational Mechanics, Volume 24, Issue 1, pp. 52-64 (1999).
(CompM Homepage);

свързани с работата ми по математическо моделиране и компютърна симулация на водонапълняеми хидротехнически мембранни конструкции.

Прилагам текста на кореспонденция с дирекция "НБИО" от НАЦИД с банковите реквизити за финансовия превод.

Дата: 28.08.2013 г. Подпис:

Веселин Илиев

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Сумата е с ДДС. Съжалявам, че не го написах.

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Уважаеми господин Николов,

Двете заявки за исканите от Вас статии са доставени в библиотеката.
Необходимо е да преведете по банковата сметка на НАЦИД следната сума:
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Банкови реквизити на НАЦИД :

BG97UNCR96603119995010

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София

Изпълнените заявки:
Title: Cascade rubber dams fall discharge calculation and analysis
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PUB. DATE: August 2011
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NOTE / NOTE

Cascade rubber dams fall discharge calculation and analysis

Qinghua Zhang and Yanfang Diao

Abstract: Cascade rubber dams fall discharge calculation and analysis is of great importance to formulate reasonable operation and control schemes of cascade rubber dams. This paper, on the principles of weir flow and water balance, puts forward single and cascade rubber dams fall discharge calculation method that facilitates cascade rubber dams fall discharge process and maximum discharge. This paper, by sample calculation of cascade rubber dams fall discharge, analyses rubber dam fall velocity, duration and other factors that influence maximum discharge and has discovered the law of cascade rubber dams fall maximum discharge.

Key words: cascade rubber dams, operation and control, fall discharge.

Résumé : Le calcul et l'analyse des décharges en chute de vannes gonflables en cascade sont très importants dans la formulation d'une exploitation raisonnable et des schémas de commande valables pour des vannes gonflables en cascade. Le présent article est basé sur les principes de l'écoulement en déversoir et l'équilibre hydrique et il avance une méthode de calcul des débits en chute libre pour les vannes gonflables simples et en cascade; cette méthode facilite le processus de décharge en chute libre des vannes gonflables en cascade et permet un débit maximum. Cet article, par le calcul d'échantillons de débits en chute libre des vannes gonflables en cascade, analyse la vitesse de chute de la vanne gonflable, la durée et d'autres facteurs qui influencent la décharge maximale. Nous avons découvert la loi de décharge maximale en chute des vannes gonflables en cascade.

Mots-clés : vannes gonflables en cascade, exploitation et commande, décharge en chute.

[Traduit par la Rédaction]

1. Introduction

Rubber dam is a new type of hydraulic structure that has appeared with the development of high molecular synthetic material featured for its low investment, simple structure, nonresistance to water, and large span. Since its application to the world's first rubber dam in Los Angeles River of USA in 1957, rubber dam has found wide application in many countries of the world. The rapid development of the rubber dam is owed to rubber dam technique research by experts and scholars. With great research achievements made in rubber dam construction techniques, including the production of rubber bags, the vibration of rubber bags, the deformation and security of water-filled rubber bags etc, more and more experts and scholars begin to attach importance to research in operation and management of rubber dam.

Kahl and Ruell 1989, Conrad and Muldoon 1995, Plaut et al. 1998, and other experts made researches on automatic observation and automatic control of rubber dam operation parameters. Tian 2008 performed research on pilot rubber dam safe operation management automatic system with decision-making support system and put forward a rubber dam safe operation management automatic system for safe operation of rubber dam. Tam and Zhang 1999 and Zhang et al. 2002 put forward problems and problem solutions in all stages of rubber dam construction, operation, and maintenance. Xu et al. 2008 made probes into rubber dams flood control operation in flood season and put forward principles for rubber dam flood control operation in flood season. Li 2007 performed research on comprehensive management and utilization of Jiaonan City Fenghe cascade rubber dams and put forward rubber dam operation and control method. Wu and Meng 2010 made probes into joint operation of Anyang City Henghe River cascade rubber dams and put forward Henghe River joint operation requirements and precautions.

With increase of rubber dams constructed, there are numerous cascade rubber dams constructed in the same river course and operation and control of cascade rubber dams constitutes a problem. At the advent of flood water in flood season, rubber dam fall must be completed before the arrival

Received 14 January 2011. Revision accepted 17 May 2011. Published at www.nrcresearchpress.com/cjce on 19 August 2011.

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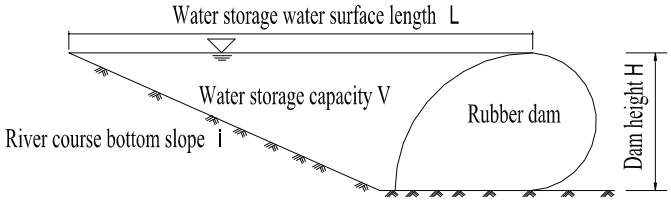
Written discussion of this note is welcomed and will be received by the Editor until 31 December 2011.

Fig. 1. Rubber dam sketch.



of flood water and dam front water flow must be staggered with upper stream peak so as to avoid increase in natural flood flow by man (Zhang 2008; Xing 2009). So, rubber dam operation and control scheme is of great importance to rubber dam, especially to cascade rubber dams discharge, and to the safety of project and lower reach river course in flood season.

One of the essential factors in formulating a scientific and reasonable rubber dam operation and control scheme is analysis of rubber dam fall discharge law, particularly the maximum discharge and the time of occurrence at the time of rubber dam fall. Research in this field is still lacking. On weir flow theory and water balance principle, this paper puts forward single and cascade rubber dams fall discharge calculation methods, analyses sample rubber dam fall discharge rules to provide references to engineering management institutions in formulating scientific and reasonable rubber dam control and operation.

2. Single rubber dam fall discharge calculation

To facilitate discussion, an analysis is made of a rubber dam upstream of a regular river course and width as shown in Fig. 1.

2.1. Dam upstream storage capacity

Based on Fig. 1, rubber dam upstream storage capacity is calculated as follows.

Rectangle cross-section river course

$$[1] \qquad V = \frac{H}{2}LB = \frac{HH}{2\ i}B = \frac{H^2}{2i}B$$

Trapezoidal cross-section river course

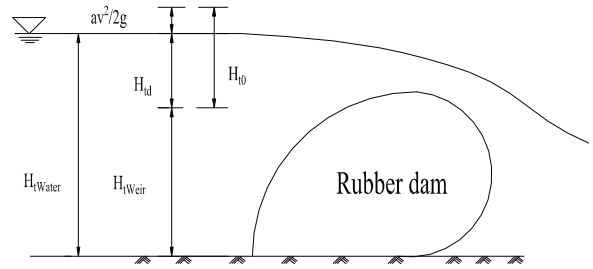
$$[2] \qquad V = \frac{(B+nH)H}{2}L = \frac{(B+nH)H^2}{2i}$$

where V is storage capacity, m^3; L is dam upstream storage section water surface length, m; H is dam water retaining height, m; B is river course width, m; n is river course side slope; and i is river course bottom slope.

2.2. Rubber dam discharge calculation basic formula

Rubber dam operation is categorized into 3 modes: (1) normal water retaining, (2) slow dam fall, (3) and complete dam fall. Dam top (bag surface) discharge is categorized into 2 flow statuses: (1) complete dam fall deemed as broad-top weir and (2) rubber dam fully inflated for normal water retaining and slow dam fall with dam bag similar to practical weir, deemed as practical weir. Therefore, rubber dam discharge could be calculated in weir flow formula

Fig. 2. Rubber dam weir head calculation sketch.



$$[3] \qquad Q_t = m\varepsilon\sigma B\sqrt{2g}H_{t0}^{3/2}$$

where Q_t is rubber dam discharge at time t, m^3/s; m is discharge coefficient; ε is lateral contraction coefficient; σ is immerging coefficient; B is flow cross-section (rubber dam) net width, m; and H_{t0} is weir head in calculation of approach velocity at time t, m.

2.2.1. Calculation of weir head before complete rubber dam fall

Weir head at time t after dam fall is as shown in Fig. 2, calculated in the following formula

$$[4] \qquad H_{t0} = H_{t\mathrm{d}} + \frac{\alpha V_t^2}{2g} = H_{t\mathrm{Water}} - H_{t\mathrm{Weir}} + \frac{\alpha V_t^2}{2g}$$

where H_{t0} is weir head at time t, m; $H_{t\mathrm{d}}$ is weir (dam bag) water depth at time t, m; $H_{t\mathrm{Water}}$ is weir front water depth at time t (from rubber dam bottom), m; $H_{t\mathrm{Weir}}$ is rubber dam water retaining height at time t, m; V_t is approach velocity of rubber dam upstream flow at time t, m/s; and α is dynamic energy correction factor.

In rubber dam fall process, with the continuation of dam fall time, rubber dam height gradually decreases and dam upstream water storage capacity and dam upstream water depth decrease accordingly with dam bag fall velocity.

If rubber dam water retaining height is H (before dam fall), with even dam fall and dam fall velocity S (m/s), then rubber dam water-retaining height at time t is

$$[5] \qquad H_{t\mathrm{Weir}} = H - S \times t$$

Dam upstream storage capacity in time interval t is

$$[6] \qquad V_t = V_{t-1} - Q_{t-1} \times \Delta t$$

where V_t is dam upstream storage capacity at time t, m^3; V_{t-1} is dam upstream storage capacity at time $t-1$, m^3; Q_{t-1} is average flow at time $t-1$ is rubber dam average discharge in the time duration Δt, m^3/s; Δt is time duration length, s.

From eq. [1], weir front water depth $H_{t\mathrm{Water}}$ of rectangular river course at time t is

$$[7] \qquad H_{t\mathrm{Water}} = \sqrt{\frac{2V_t \times i}{B}}$$

From eq. [2], weir front water depth $H_{t\mathrm{Water}}$ of trapezoidal river course at time t is

$$[8] \quad nH_{t\text{Water}}^3 + BH_{t\text{Water}}^2 = 2V_t \times i$$

2.2.2. Weir head calculation after complete rubber dam fall

With complete rubber dam fall and continuation of flow time, dam upstream storage capacity and weir water depth gradually decrease. Weir head at time t could still be calculated in eq. [4], with $H_{t\text{Weir}} = 0$.

2.2.3. Rubber dam discharge coefficient

Rubber dam overflow is between broad-top weir and practical weir. Before and during rubber dam fall, its overflow could be calculated as curve-type practical weir with discharge coefficient 0.36–0.45. After complete rubber dam fall, it could be calculated as broad-top weir with discharge coefficient 0.33–0.36 (The Ministry of Water Resources of the Peoples Republic of China 1999).

2.3. Irregular river course

Water storage capacity of irregular river course could not be calculated in eqs. [1] or [2]. Therefore, weir front water depth at time t $H_{t\text{Water}}$ could not be calculated in eqs. [7] or [8] and should be obtained by calculating V_t from eq. [6] and by referring to relation curve of storage capacity-weir front water level (V~H). Other calculations are the same as those of regular river course.

2.4. Calculation method

Calculation of discharge in the process of rubber dam fall should be done at time-intervals. The calculation should proceed in the following order: first, deciding basic parameters of rubber dam and river course such as time duration length Δt and dam bag fall velocity, then calculation of $H_{t\text{Weir}}$ after dam fall (rubber dam water retaining height) of each time-interval with rubber dam normal water retaining as the first time-interval, dam upstream water storage capacity V_t, rubber dam front cross-section water depth, weir front water depth $H_{t\text{Water}}$ and weir head H_{t0}, rubber dam discharge Q_t. It should be explained that rubber dam discharge calculation accuracy is related to selected time duration length Δt and to ensure calculation accuracy, time duration length Δt should not be too long, the proper length being 30-60s.

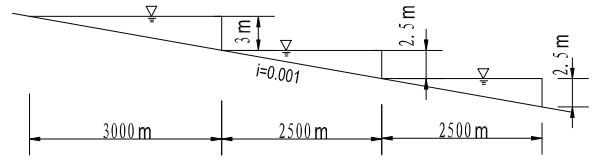
3. Cascade rubber dam discharge calculations

3.1. Analysis of upstream rubber dam discharge on downstream rubber dam discharge

Upstream rubber dam discharge impact on downstream rubber dam discharge depends on a number of major factors such as the distance between upstream rubber dam and downstream rubber dam, rubber dam fall starting time and dam fall velocity. In the following cases, upstream dam discharge exercises no impact on downstream rubber dam discharge.

1. Long distance between the two rubber dams, where the arrival of upstream rubber dam discharge finds complete discharge of downstream dam stored water with downstream rubber dam fall.
2. Despite the short distance between two rubber dams, downstream rubber dam stored water has been completely drained with completion of dam fall when upstream rubber dam discharge (dam fall) starts.

Fig. 3. River course cascade rubber dam sketch.



With upstream rubber dam discharge impact on downstream rubber dam discharge, downstream rubber dam discharge increases. But, as there is a distance between two rubber dams, it takes time for upstream rubber dam discharge to reach downstream rubber dam and therefore discharge of upstream rubber dam could not be simply added to the discharge of downstream rubber dam discharge. Its impact may be calculated by increase in downstream rubber dam capacity with completion of upstream rubber dam discharge.

3.2. Downstream rubber dam discharge calculation

In considering upstream rubber dam impact on downstream rubber dam discharge, rubber dam discharge could still be calculated in the abovementioned method with consideration given to water quantity of upstream rubber dam discharge in eq. [6]. With the time for upstream rubber dam discharge to reach downstream rubber dam as T, rubber dam upstream water storage capacity at time t could be calculated in the following formula

$$[9] \quad V_t = V_{t-1} - Q_{t-1} \times \Delta t + Q_{t-n}^u \times \Delta t$$
$$K = \frac{T}{\Delta t}$$

where Q_{t-n}^u is upstream rubber dam discharge in t-k duration (m^3/s); k is the number of durations (round number) between starting of upstream rubber dam discharge and its arrival at downstream rubber dam; and T is the duration between upstream rubber dam discharge starting and its arrival at downstream rubber dam (s).

4. Case study

A 3-step rubber dam is constructed in the urban section of a river course as shown in Fig. 3 with river course bottom slope 1/1000, a rectangular cross-section, river course width 50 m, first-step rubber dam height 3.0 m, water storage capacity 225 000 m^3, second-step and third-step rubber dam height 2.5 m, water storage capacity 156 250 m^3. The process and maximum flows of different dams with different dam fall velocity and dam fall scheme are calculated (with supposed absence of upstream water and short distance between rubber dams and with no consideration given to the duration between upstream dam discharge and its arrival at downstream rubber dam).

4.1. Rubber dam fall scheme

Rubber dam fall is performed in an upward order with dam fall scheme as shown in Table 1.

In Table 1, rubber dam fall schemes 1, 5, and 9 are three schemes for third-step dam simultaneous falls and other

Table 1. Rubber dam operation scheme table.

	Complete dam fall time (h)			Dam fall starting time (h)		
Scheme	1st step dam	2nd step dam	3rd step dam	1st step dam	2nd step dam	3rd step dam
1	3	2.5	2.5	0	0	0
2	3	2.5	2.5	1	0.5	0
3	3	2.5	2.5	2	1	0
4	3	2.5	2.5	5	2.5	0
5	2.5	2	2	0	0	0
6	2.5	2	2	1	0.5	0
7	2.5	2	2	2	1	0
8	2.5	2	2	5	2.5	0
9	1.5	1	1	0	0	0
10	1.5	1	1	1	0.5	0
11	1.5	1	1	2	1	0
12	1.5	1	1	2.5	1	0
13	No dam fall	1	1		1	0

Table 2. Rubber dam maximum discharge calculation table in different dam fall schemes.

	1st step dam		2nd step dam		3rd step dam	
Scheme	Maximum discharge (m^3/s)	Occurrence time	Maximum discharge (m^3/s)	Occurrence time	Maximum discharge (m^3/s)	Occurrence time
1	32.3	1 h 09 min	58.7	1 h 19 min	85.4	1 h 29 min
2	32.3	2 h 09 min	53.8	2 h 11 min	71.6	2 h 13 min
3	32.3	3 h 09 min	47.8	3 h 06 min	47.6	3 h 10 min
4	32.3	6 h 09 min	32.3	6 h 12 min	32.3	6 h 12 min
			(26.9)	(3 h 30 min)	(26.9)	(1 h 03 min)
5	38.0	1 h 03 min	70.2	1 h 11 min	103.1	1 h 20 min
6	38.0	2 h 03min	54.8	2 h 00 min	75.0	2 h 00 min
7	38.0	3 h 03min	54.8	3 h 00 min	53.7	3 h 00 min
8	38.0	6 h 03min	38.0	6 h 03 min	38.0	6 h 03 min
			(32.8)	(3 h 24 min)	(32.8)	(0 h 53 min)
9	60.0	0 h 48min	119.7	0 h 51 min	190.6	1 h 00 min
10	60.0	1 h 48min	87.8	1 h 30 min	98.0	1 h 00 min
11	60.0	2 h 48min	60.0	1 h 37 min	60.0	0 h 37 min
12	60.0	3 h 18min	60.0	1 h 37 min	60.0	0 h 37 min
13			60.0	1 h 37 min	60.0	0 h 37 min

Note: The occurrence time starts from third-step (lowest stream) rubber dam fall; Data in the bracket are maximum discharge and occurrence time during rubber dam fall period.

schemes are upward dam fall schemes in certain duration. Scheme 13 is for the case of two rubber dams falls of the same kind.

4.2. Calculation of different rubber dams in different schemes

In the selected rubber dam fall scheme, time-interval is 30 s and discharge coefficient before rubber dam complete fall is selected in the range 0.36–0.45 and lateral contraction coefficient is 0.95, with no consideration given to duration between upstream rubber dam discharge starting and its arrival at downstream rubber dam. Calculation of maximum flow and flow occurrence time of different rubber dams in the abovementioned calculation methods are as shown in Table 2. Figure 4 shows third-step rubber dam discharge hydrograph in scheme 7 and Fig. 5 shows second-step rubber dam discharge hydrograph in scheme 13.

4.3. Analysis of rubber dam discharge rules

Analysis of the calculation results in Table 2 leads to the discovery of the rules of cascade rubber dams fall discharge as follows:

1. At the same dam fall time of cascade rubber dams, the shorter duration of upward dam falls, the greater impact of upstream rubber dam discharge on downstream rubber dam discharge and the greater discharge of downstream rubber dam. With the same dam fall time in schemes 1–4, scheme 1 shows simultaneous dam fall of third-step rubber dam with third-step rubber dam maximum discharge 85.4 m^3/s. Scheme 2 shows time lagging in first-step and second-step rubber dam fall compared with third-step rubber dam fall with third-step rubber dam maximum discharge 71.6 m^3/s, lower than that in scheme 1. Time lagging of first-step and second-step rubber dam fall, greater than that in scheme 2, with third-step rubber dam

Fig. 4. Third-step rubber dam flow hydrograph in scheme 7.

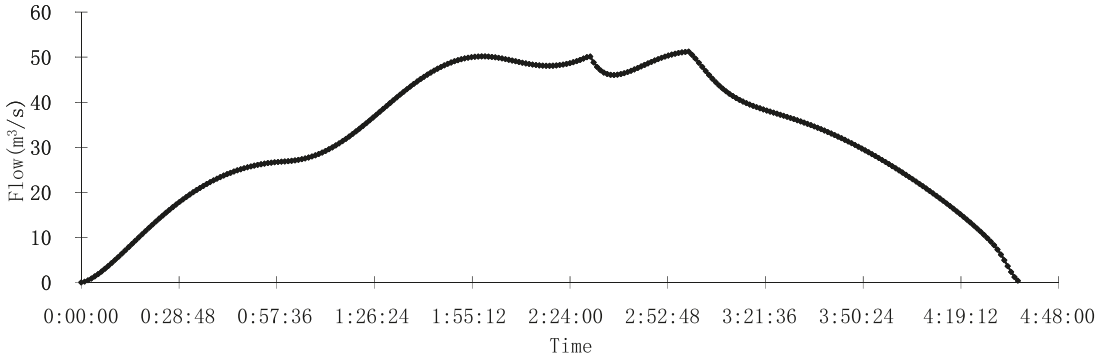
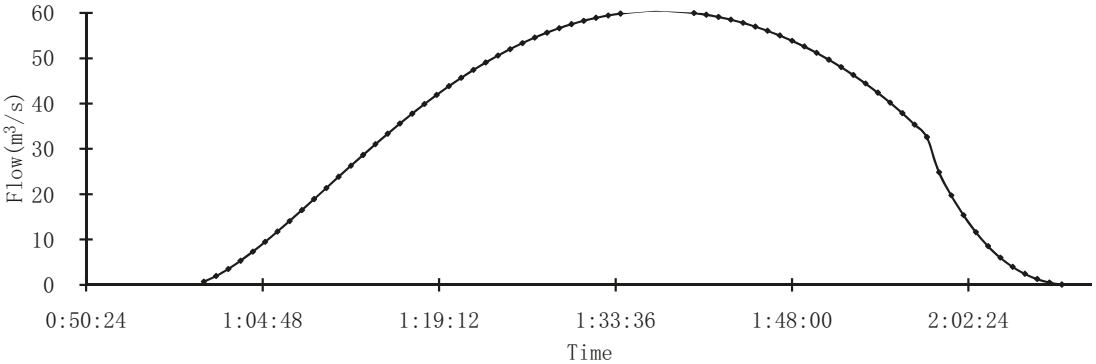


Fig. 5. Second-step rubber dam flow hydrograph in scheme 13.



maximum discharge 47.6 m^3/s, less than that in scheme 2. Time lagging of first-step and second-step rubber dam fall in scheme 4 is greater than that in scheme 3 with third-step rubber dam maximum discharge 32.3 m^3/s, less than that in scheme 3. Calculation results in other schemes are the same.

2. With the same duration of cascade rubber dam upward dam fall, the shorter the rubber dam fall time (the greater velocity of dam fall), the greater the rubber dam fall maximum discharge. With the same rubber dam fall duration in schemes 2, 6, and 10, rubber dam fall duration is maximum in scheme 2, followed in priority by scheme 6 and scheme 10. Maximum discharge of first, second and third step rubber dam falls is in an ascending order in scheme 2, scheme 6, and scheme 10. In third-step rubber dam, the maximum discharge is in an ascending order, 71.6 m^3/s in scheme 2, 75.0 m^3/s in scheme 6, and 98.0 m^3/s in scheme 10.
3. With completely the same conditions of two rubber dams and the same dam fall time of upstream rubber dam fall duration equal to downstream rubber dam complete dam fall time, upstream rubber dam exercises no impact on downstream rubber dam maximum discharge, where rubber dam maximum discharge depends on upstream water storage quantity and dam fall time. As in scheme 13 in Table 2, third-step rubber dam fall time is 1 h and upstream second-step rubber dam fall duration is 1 h, with the same maximum discharges 60.0 m^3/s of two rubber dams.
4. With upstream rubber dam size (storage capacity) greater than that of downstream rubber dam and with upstream rubber dam duration greater than that of downstream rubber dam complete fall time, upstream rubber dam still exercise impact on downstream rubber dam discharge, where downstream river course maximum discharge is dependent on upstream rubber dam (river course) maximum discharge with time lagging of maximum discharge occurrence, as the case in Table 2, where second-step and third-step rubber dam maximum discharge and that of first-step rubber dam are the same in schemes 4, 8, and 12.
5. With the impact of upstream rubber dam discharge, downstream rubber dam discharge process is in a multiple peak curve (Fig. 4); single rubber dam discharge process is in single peak curve (Fig. 5).

5. Conclusion and suggestions

These analyses lead to the following conclusions:

1. The discharge in the process of cascade rubber dam fall is a continuous process, in the engineering design of which calculation may be performed by time-intervals and the shorter the time interval, the more accurate the calculation result.
2. The shorter the duration of upward cascade rubber dams fall, the stronger the impact of upstream rubber dam fall discharge on downstream rubber dam fall discharge.
3. The most important factors in dam fall discharge are rubber dam fall velocity. The greater the dam fall velocity and shorter the time, the greater maximum dam fall discharge. Example: On 18 August 2009, Linyi City Yihe Gezhuang rubber dam (dam height 3 m, dam front storage capacity 7 750 000 m^3) fall time 3 h and 20 min, actual maximum discharge 646 m^3/s. Huayuan rubber dam (dam

height 2.4 m, dam front storage capacity 1 750 000 m^3), dam fall time 6 h, actual maximum discharge measured only 81 m^3/s (Zhang et al. 2010). This result has verified the conclusion in this paper.

4. In the light of conclusions (2) and (3), it is suggested that in designing cascade rubber dams fall scheme, provided that conditions of complete dam fall is satisfied before upstream flood peak arrival, dam fall duration should be as long as possible while lengthening rubber dam fall time so as to reduce "man-made flood" from rubber dam fall to ensure safety of downstream river course.

In addition to that, the method put forward in this paper may serve as a reference to application by engineering design and management institutions. As this paper is only a theoretical research, it is suggested that further research be made in hydraulic model tests.

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List of symbols

V	storage capacity
L	dam upstream storage section water surface length
H	dam water retaining height
B	river course width
n	river course side slope
i	river course bottom slope
Q_t	rubber dam discharge at time t
m	discharge coefficient
ε	lateral contraction coefficient
B	flow cross-section (rubber dam) net width
H_{t0}	weir head in calculation of approach velocity at time t
H_{td}	weir (dam bag) water depth at time t
$H_{t\mathrm{Water}}$	weir front water depth at time t (from rubber dam bottom)
$H_{t\mathrm{Weir}}$	rubber dam water retaining height at time t
V_t	approach velocity of rubber dam upstream flow at time t
Δt	time duration length