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FINAL CONFERENCE

Alliance for Disaster Risk Reduction – ALTER

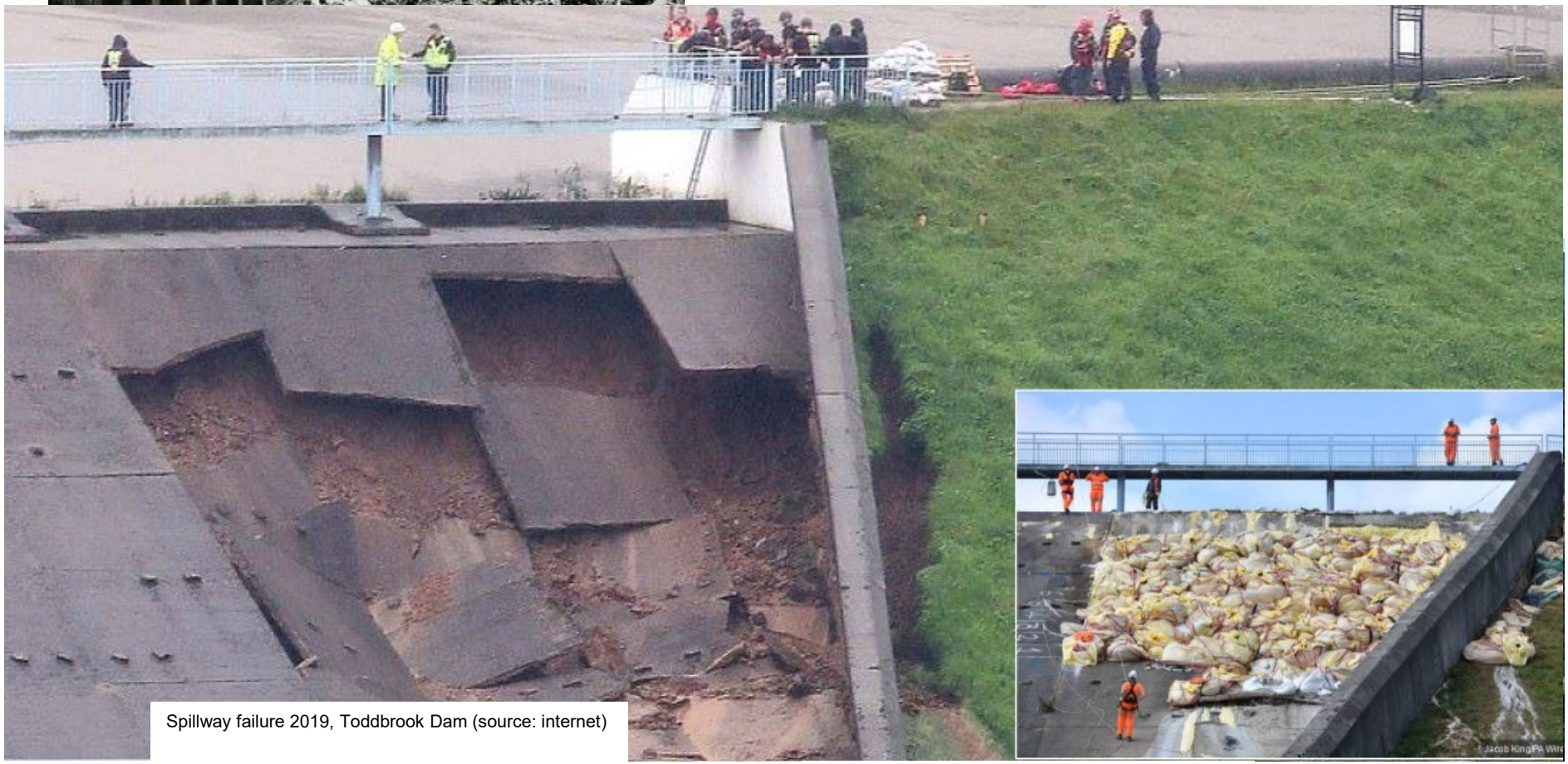
Tuesday December 10th 2019

Flash floods from Dams' failure.
Best practices in Managing the Risks

Example: Vorotan Cascade, Armenia

Contents

Risk Management, why?



Spillway failure 2019, Toddbrook Dam (source: internet)

Example Vorotan Cascade

Contour Global acquired assets of the Vorotan Cascade with a total installed capacity of 405 MW generated by three individual power plants.

The entire cascade was built between 1970 and 1989 during the Soviet period.

Spandaryan Reservoir

Tolors Reservoir

Tatev Reservoir

Example Vorotan Cascade

ContourGlobal assigned Fichtner to:

- Perform a detailed assessment of the condition of each dam structure of the cascade
- Supervise geotechnical and geophysical investigations
- Perform stability investigation and analysis of current condition of each dam structure
- Provide recommendations as regards stability improvement measures
- Revise the existing monitoring equipment
- Develop a Monitoring Plan for regular geodetic measurements and seepage control
- **Perform flood and dam break studies**
- **Develop an Emergency Action Plan for potential dam failure**

These studies are in progress, geotechnical and geophysical investigations are completed, implementation of improvements in dam monitoring is ongoing

Flood Studies

Purpose:

Checking safety of facilities related flood events

- Method of 'flood frequency analysis' has been applied for estimating the 'design flood' for each dam

Location	Design flood ($Q_{1,000yrs}$) [m³/s]	Safety check flood ($Q_{10,000yrs}$) [m³/s]	PMF [m³/s]
Spandaryan Dam	255	357	473
Angeghakot Dam	363	482	639
Tolors Dam	130	181	240
Tatev Dam	512	778	1,032

- Actual inflow and outflow flood peaks and corresponding reservoir levels at the four dam sites were estimated through reservoir routing
- Different scenarios for dams and reservoirs (n vs. n-1; reservoirs at Full Supply Level vs. Max. Operation Level) were studied

Flood Studies

- Example Tolors with reservoir initially at Max. Operation Level, with 1,000 years and 10,000 years floods.

				MaxOL						FSL					
Highest admissible water level				**Q1000**		**Q10000**		**PMF**		**Q1000**		**Q10000**		**PMF**	
Spandaryan	n	2065.00	masl	2064.17	m	2064.39	m	2064.65	m	2063.45	m	2063.65	m	2063.90	m
	n-1	2065.00	masl	2064.48	m	2064.71	m	2064.97	m	2063.63	m	2063.88	m	2064.16	m
Angeghakot	n	1683.00	masl	1680.10	m	1680.10	m	1680.10	m	1677.40	m	1677.70	m	1678.30	m
	n-1	1683.00	masl	1680.10	m	1680.10	m	1680.32	m	1679.03	m	1679.34	m	1679.72	m
Tolors	n	1653.80	masl	1652.72	m	1652.78	m	1652.87	m	1651.71	m	1651.79	m	1651.89	m
Tatev*	n	1339.00	masl	1336.95	m	1336.95	m	1337.20	m	1335.87	m	1336.06	m	1336.24	m

Reservoir Water Level uncritical
Reservoir Water Level critical but admissible for limited time
Reservoir Water Level critical

* With Consideration of Parapet Wall

Dam Break Studies

Purpose:

Studying effects of a partial or catastrophic failure of a dam which leads to an uncontrolled release of water. It may occur due to uncontrolled inflow into a reservoir, effects of disaster like landslides, earthquakes, erosion of dam material due to seepage, piping, overtopping or due to defects in embankments and foundation.

In case of the dams in the Vorotan cascade the Spandaryan, Tolors and Tatev dams are embankment dams for which the most probable dam break scenario is the gradual break due to overtopping. Angeghakot dam is a concrete gravity dam for which the most probable dam break scenario is the instantaneous or sudden failure.

The dam break study performed entails the following:

- Determining the outflow hydrograph and the peak discharge
- Routing the peak discharge and prediction of hydrograph at different sections downstream
- Mapping of inundation area
- Determining the time to peak at different location downstream.

Dam Break Studies

Input parameter for dam break modeling

While HECRAS tool has incorporated five different methods/models to estimate the breach parameters (breach bottom width, breach side slopes and breach development time), other numerous investigators have developed other models as well to predict these breach parameters based on the reservoir and dam properties and characteristics, failure modes, etc. All of these models, available till now, including those available in HEC-RAS, have been considered in this study to estimate the breach width and breach formation time for the dam failure analysis.

Breach Formation Time

Model	Breach formation time, t_f [hrs]			
	Spandaryan	Angeghakot	Tolors	Tatev
Singh and Snorrason (1982,1984)	0.25 - 1	For Concrete Gravity dam: 0.1 - 0.5 (USACE) 0.1 - 0.3 (FERC) 0.1 - 0.2 (NWS)	0.25 - 1	0.25 - 1
MacDonald and Langridge-Monopolis (1984)	3.8		2.7	1.3
FERC (1987)	0.1 - 1		0.1 - 1	0.1 - 1
Froehlich (1987)	1.2		0.9	0.6
Bureau of Reclamation (1988)	2.7		2.3	1.4
Von Thun and Gillette (1990)	1.9		1.6	1.1
	0.6		0.6	0.7
SMPDK model (1991)	1.5		1.3	0.8
Froehlich (1995)	1.5		1.0	0.6
Froehlich (2008)	1.2		0.9	0.5
Sattar (2014) - GEP models	1.9		1.7	1.4
Saberi & Genz (2015)	3.8		2.8	1.7
Considered breach development time	***1.5 hrs***	***0.3 hrs***	***1.0 hrs***	***0.5 hrs***

Dam Break Studies

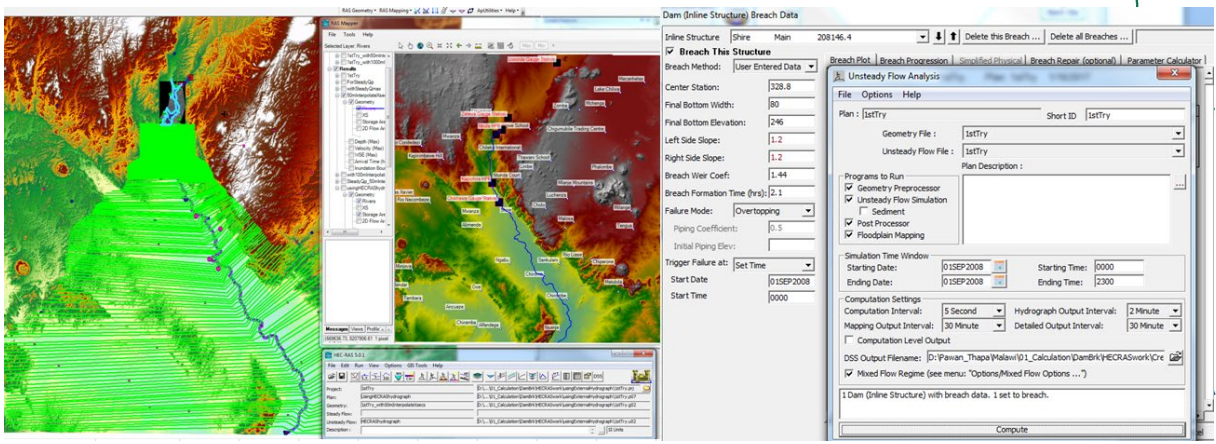
Methodology for dam break modeling

Estimated breach parameters - input to the unsteady flow HEC-RAS model. The dam - modeled as an inline structure connected at upstream to reservoir. The reservoir - modeled as a storage area defined by its elevation-volume curve and provides the upstream boundary condition to the model.

The downstream end of model set-up - taken sufficiently far enough for the flood routing & inundation mapping - about 150 km downstream from the Spandaryan dam - where the normal flow depth can be safely given as the downstream boundary condition of the model.

The required river profile and the river cross-sections data completely encompassing the possible inundated area is extracted from the DEM of the area – created from SPOT 6 and SPOT 7 high-resolution satellite data & SRTM DEM data

ArcGIS & HEC-GeoRAS are used for the pre- & post-processing and HECRAS is used for the modelling of dam breach, propagation of the ensuing dam break outflow hydrograph downstream along with the mapping of the inundation in the flood plain along the river course

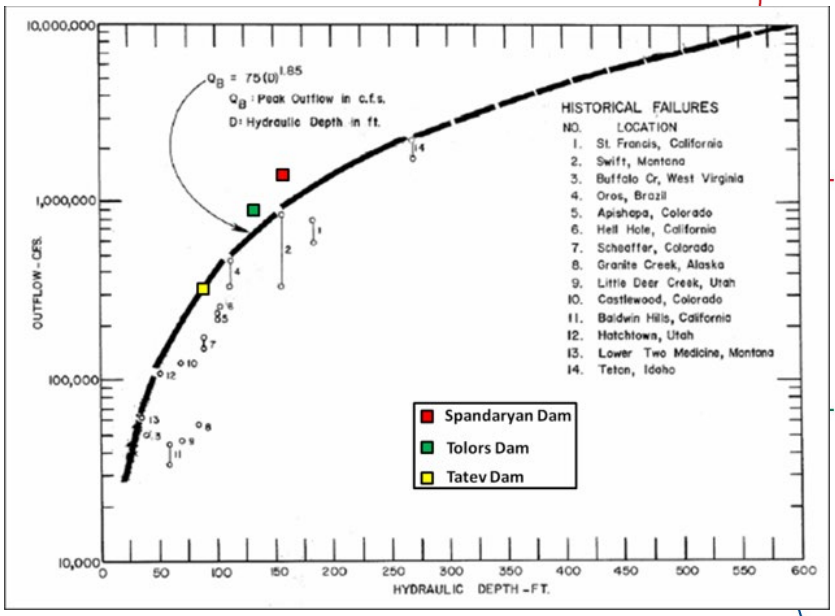


Dam Break Studies

Results – Plausibility check of flood outflow

Several peak flow regression models have been developed from historic dam failure data at different times. These models have been used for several dam safety studies. The dam break outflow peak computed from HEC-RAS is compared to the peak floods from those observed failure-data-based regression equations as a test for reasonableness.

Models	Peak Outflow, Qp [m³/s]			
	Spandaryan	Angeghakot	Tolors	Tatev
Singh and Snorrason (1984)	17,127	Not applicable for Concrete Gravity dam	10,869	4,444
MacDonald and Langridge-Monopolis (1984)	21,999		13,780	5,222
Costa (1985)	22,645		14,057	5,227
Evans (1986)	22,398		13,412	4,892
Froehlich (1995)	**45,127**		**27,552**	**8,971**
Xu & Zhang (2009)	**42,728**		**22,474**	**5,305**
Pierce et al. (2010)	30,824		24,034	11,659
	19,001		9,241	2,239
	34,764		17,472	4,193
	48,996		25,773	6,376
Saberi & Genz (2015)	42,940		22,301	5,442
Instantaneous Failure Peak (*Analytical*)	44,159		29,432	8,962
SMPDBK model/ Wetmore & Fread (1984) (*Analytical*)	33,363		21,331	6,386
Peak outflow of the estimated breach Hydrograph (HECRAS)	***45,291***	***8,491***	***25,201***	***8,478***



The plausibility checks indicate that the dam break outflow hydrographs simulated by the HEC-RAS model for the dams in the Vorotan cascade are appropriate and reasonable estimates

Dam Break Studies

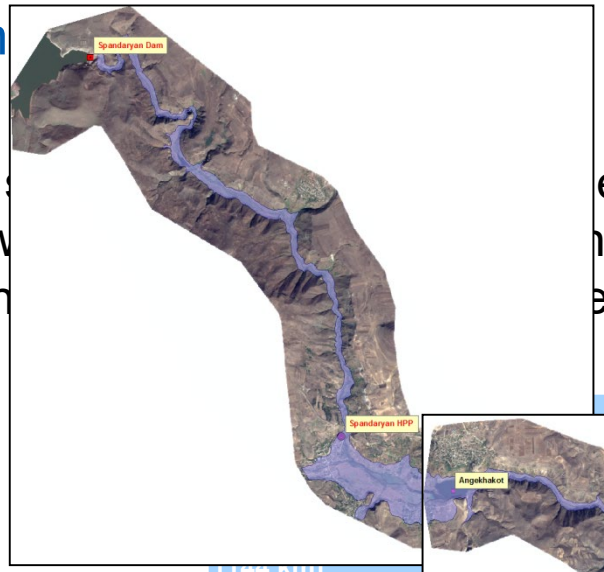
Results

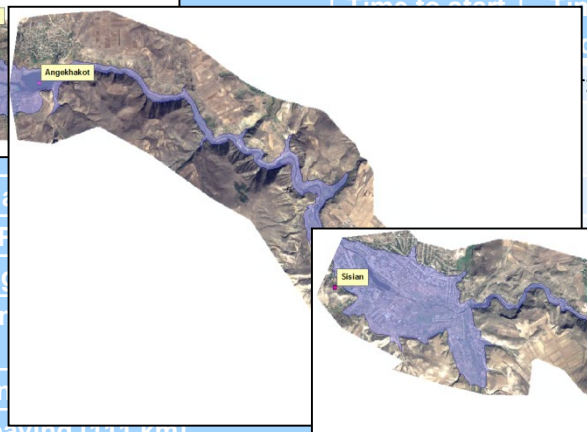
The dam break study/modeling provides the following output:

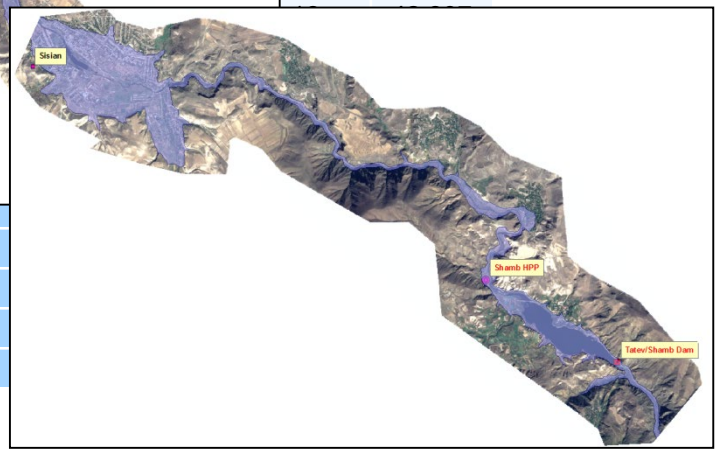
- Outflow hydrograph and the peak discharge
- Attenuation of the peak flood through routing & prediction of hydrograph at different sections downstream
- Mapping of inundation area
- Maximum Flood depth
- Maximum channel velocities
- Timing of flood wave - determining the runoff time of the peak discharge at different sections downstream

Dam Break Studies

Dam







As a s e Spandaryan and Tatev dam failure, the follow nen the flooding starts, time when the flood peak reach e peak flood at different locations of the interest.

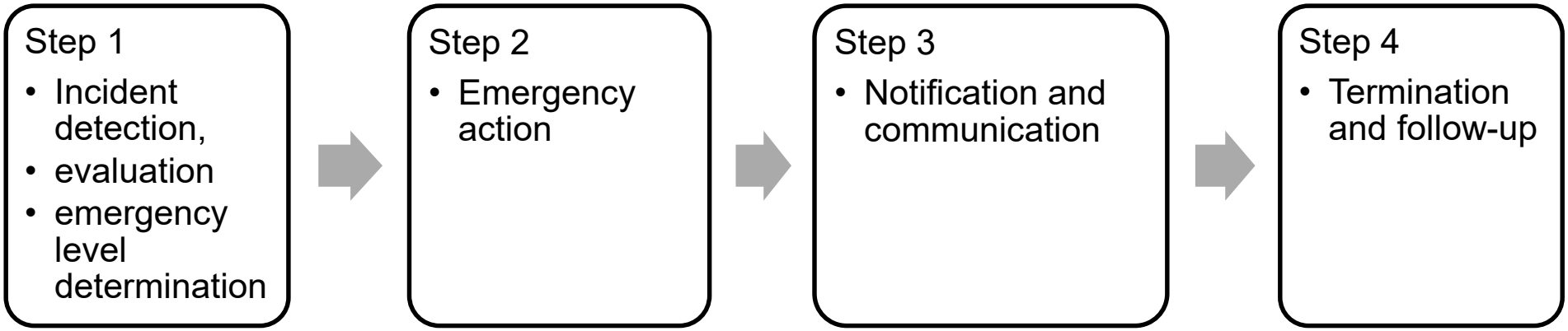
	Time to start	Time to d peak	Flood peak
		:min	m³/s
[144 km]			
Spandaryan Villa		:02	45,391
At Spandaryan H		:15	43,217
Balak and Angeg			
Just downstrea [124 km]			
At Sisian City en			
At Sisian City leaving [111 km]			
At Shamb Powerhouse [98.5 km]			
Just downstream of Tatev Dam [95 km]			
At Tatev Powerhouse [67 km]			
Downstream end (Yeritsvank) [0 km]			

Emergency Planning

Purpose:

Specification of roles, responsibilities and actions to be taken by individual stakeholders to reduce risk and potential los of life based on dam break studies results.

In case of an emergency event, 4 main steps were identified:



Emergency Planning

Step 1: Incident Detection, Evaluation, and Emergency Level Determination

Sources of the detection

- Monitoring and operating information available at dam
- Usual inspection procedures (O&M procedures)
- Existing dam studies (stability, monitoring report, technical detailed report, hazard assessment…)

Type of incident

- Instrument values out of normal range
- Earth Spillway Flow
- Embankment Overtopping
- Seepage
- Sinkholes
- Embankment Cracking
- Embankment Movement
- Earthquake
- Security Threat
- Sabotage/ Vandalism
- …

Emergency level categories

Non-Failure	unusual situation at the dam, not leading to a potential failure of the dam.
Potential Failure	unusual situation of the dam that could lead to an imminent failure of the dam.
Imminent Failure	failure of the dam has or will occur in a close future.

Step 2: Emergency Actions for Staff in duty at Tolors Dam (Example)

Event	n°	Description of situation	Criteria	Process for confirming observation	Emergency Level
Earthquake	15	Measurable earthquake felt or reported on or within 50 km of the dam. No visible damage to the dam	Reported by local authorities, local inhabitants or felt at dam site. Strong Motion Accelerometers < 0.3 m/s²		Non-failure
	16	Strong earthquake or earthquake resulted in visible damage to the dam or appurtenances. Controllable damages not leading to release of water	Visual checking Strong Motion Accelerometers: • > 0.3 m/s² • And < 0.6 m/s²	Double check reading at Strong Motion Accelerometers Send value to Head of Civil Works Reinforced monitoring and new stability check verifications	Potential failure
	17	Exceptional intensity earthquake or Earthquake resulted in uncontrolled release of water from the dam	Visual checking Strong Motion Accelerometers > 0.6 m/s²	Send pictures to Head of Civil Works for confirming Maximum wait for answer is 10 minutes.	Imminent failure

Emergency Planning

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Emergency Level	Action to be taken
Non-failure	1. Make notifications according to flowchart 2. Forbid traffic on dam crest for everyone (use alternative way to come to the dam). 3. Assess extent of damage and visually inspect entire dam. 4. Perform additional tasks as directed by Dam Engineer.
Potential failure	1. Make notifications according to flowchart 2. Lower reservoir level : ask Angeghakot dam to stop inflow and Shamb HPP to increase discharge/outflow 3. Forbid traffic on dam crest for everyone (use alternative way to come to the dam). 4. Assess extent of damage and visually inspect entire dam. 5. Perform additional tasks as directed by Dam Engineer.
Imminent failure	1. Trigger Water Alarm System for immediate evacuation of downstream population 2. Make notifications according to flowchart 3. Lower reservoir level : ask Angeghakot dam to stop inflow and Shamb HPP to increase discharge/outflow 4. Forbid traffic on dam crest for everyone (use alternative way to come to the dam). 5. Assess extent of damage and visually inspect entire dam. 6. Perform additional tasks as directed by Dam Engineer.

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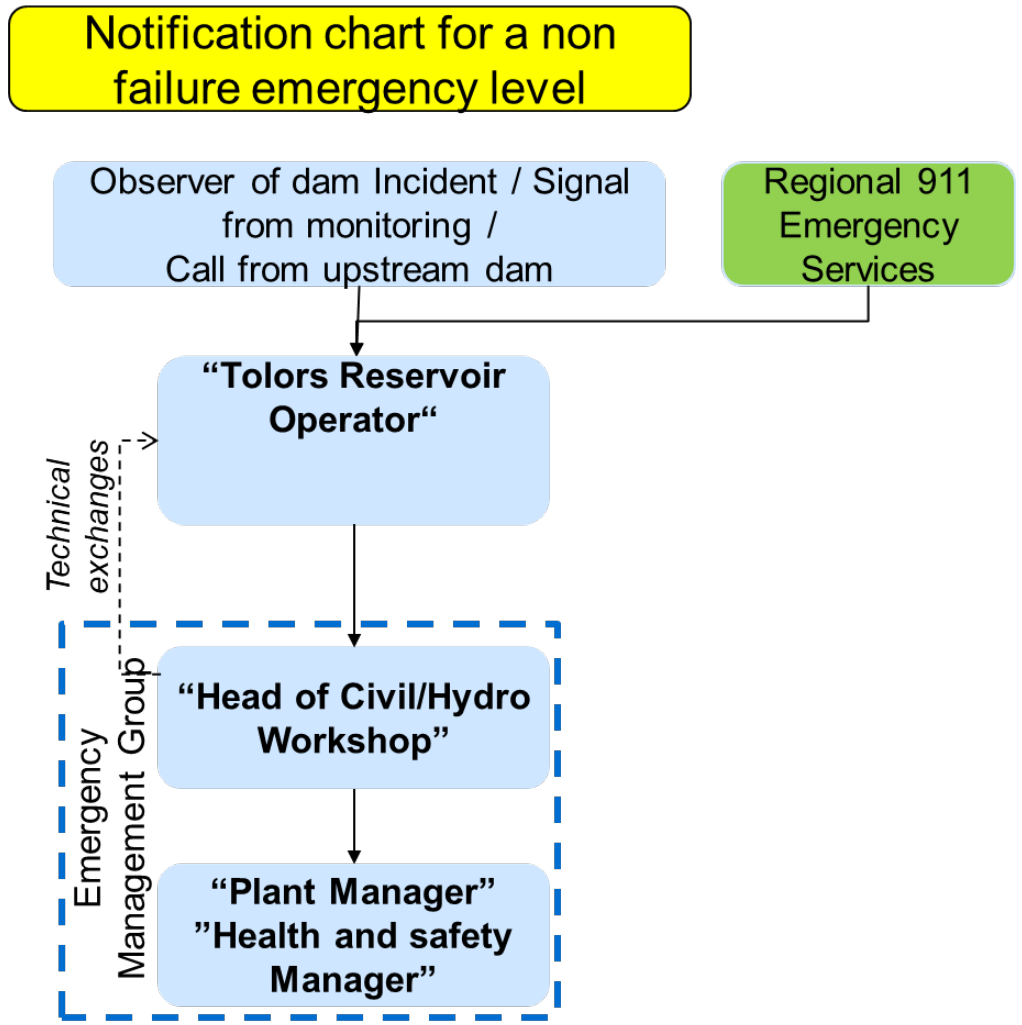
Step 3: Notification and Communication

→ 3 notification flowcharts depending on the emergency level category



Emergency Planning

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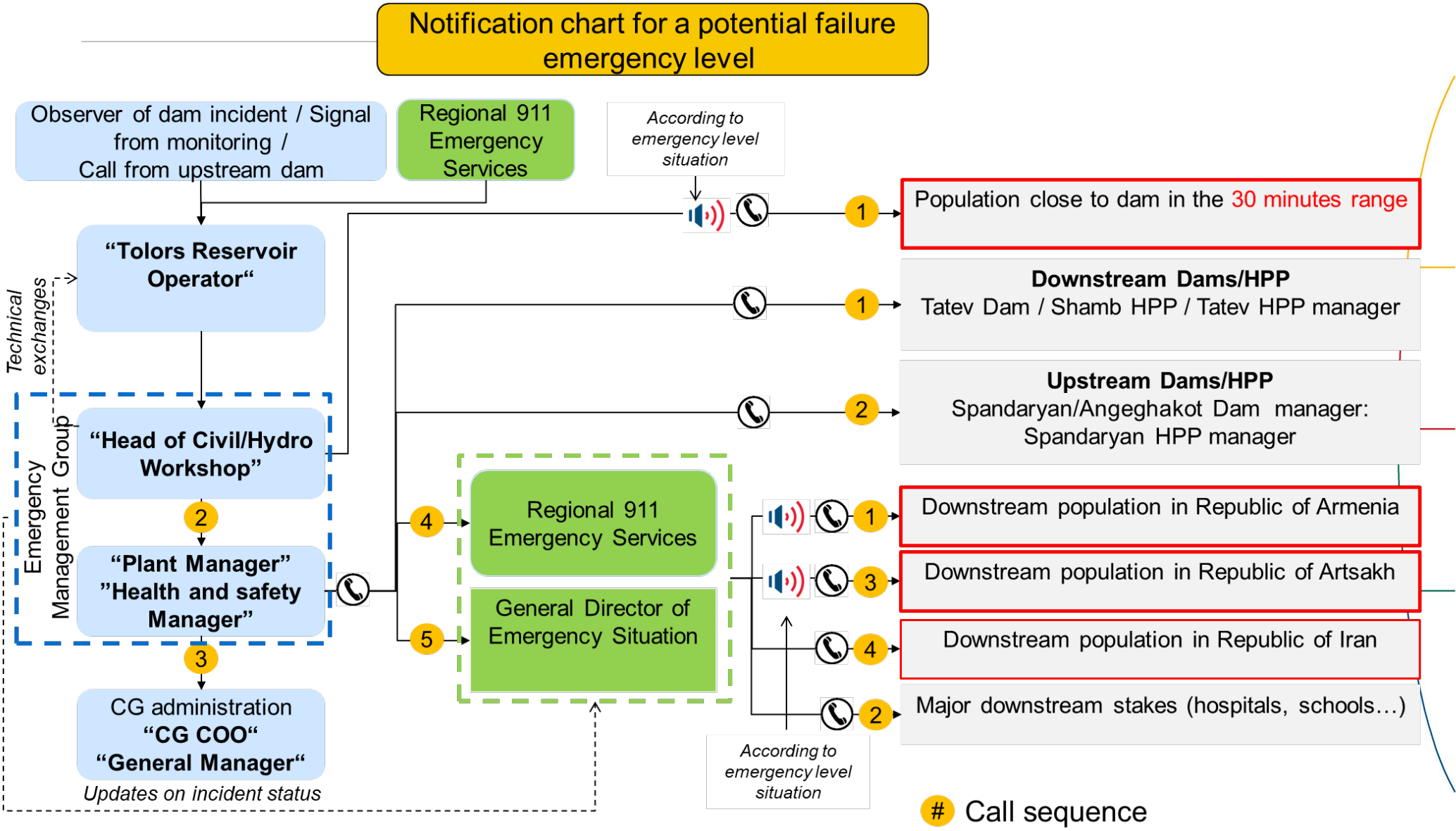

Emergency Planning

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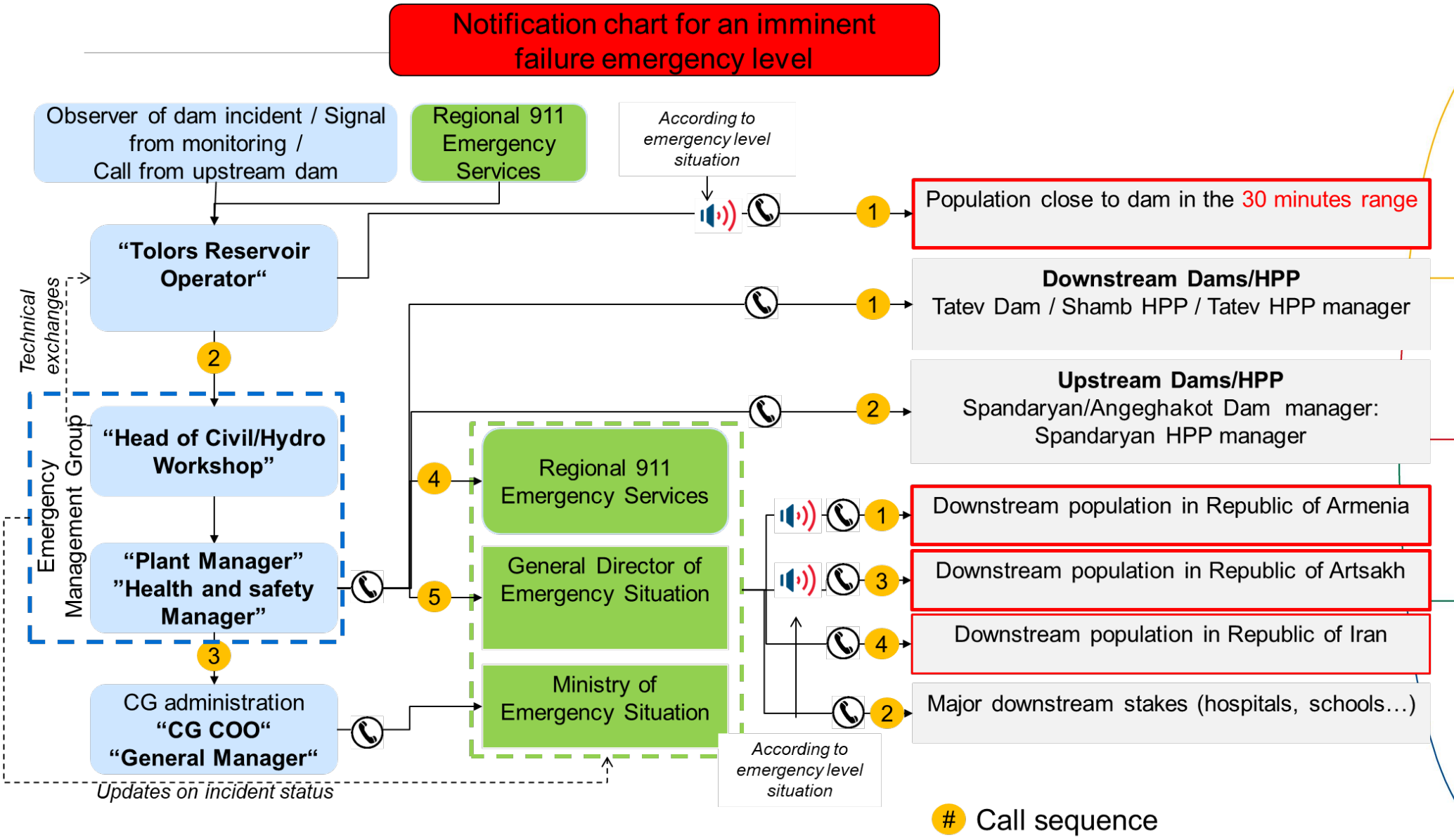
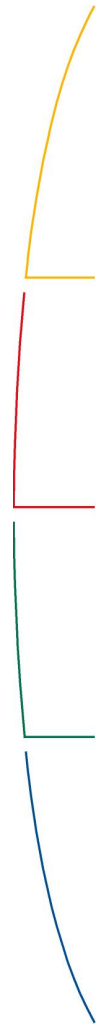


Emergency Planning

Step 4: Termination and Follow-Up

	Step	Who	How	To whom
TERMINATION	1. Criteria for determining closing of the incident	Head of Civil Works/dam safety	Criteria to determine Emergency Category level are not reached any more	• Reservoir operator • General manager
	2. Incident log to be filled	Head of Civil Works/dam safety	Fill the document : ***Dam Emergency Termination Log*** (see appendix)	
	3. Transmission of the document to officials	General Manager	Mail, phone	• Emergency management authorities • Ministry of Emergency Situation
	4. Declaring an end to public emergency response	Emergency management authorities	Siren, radio, phone	• all warned areas
FOLLOW-UP	5. Closing evaluation	• Contour Global Emergency management Group • Emergency management authorities • Ministry of Emergency Situation	• Events or conditions leading up to, during, and following the incident • Significant actions taken by each participant and improvements for future emergencies • All strengths and deficiencies found in the incident management process, materials, equipment, staffing levels, and leadership • Corrective actions identified and a planned course of action to implement recommendations	Internal use for revising EAP and improving response process and communication with emergency management authorities
	6. Report on the incident	Contour Global	Fill the documents : *1-* ***After Action Report***, based on the closing evaluation 2- ***Record of Emergency Plan Holders*** (see appendix) *3-* ***Record of Reviews and Revisions*** (see appendix)	Internal use for revising EAP

Thanks for your attention



Discussion