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Practical Case Study

APPLICATION OF RISK INDEXING TOOL FOR EVALUATION OF CONSTRUCTED DAM SAFETY IN JAVA

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Abstract: A risk indexing tool (RIT) was used for ranking constructed dam safety under limited instrumentations and insufficient data available for the constructed dam. The risk indexing tool was based upon identification of potential deficiencies of the dams and their physical environment, and rating of the overall importance of these conditions. The study area covered 8 dams in West Java, 24 dams in Central Java, and 13 dams in East Java. None of potential deficiencies of the dams was risky. Slope stability in upstream side has to be addressed to 3 dams in West Java. Slope stability in downstream side has to be addressed to 1 dam in Central Java and 3 dams in East Java. Soil erosion and animal holes prevention have to be provided for those dams. A number of 3 dams in East Java require further investigation on the prevention methods. Therefore, physical environmental conditions outside the dams have the highest priority for preventive measures against failure.

Keywords: Dam safety, initial importance factors, relative importance factors, risk ranking

INTRODUCTION

In Indonesia, hundreds of large dams and hydraulic structures had been built since 1900. The dams were constructed only to fulfil the irrigation purposes. Currently, the dams are utilized as a multipurpose dam, namely as a power house of electrical energy, fresh water supply and/or flood control. The dams have to be monitored for their safety to prevent environmental damage as well as human being who live in their downstream area. Geotechnical instruments are generally installed to monitor the performance of dams periodically in addition to on-site inspection. The possible risk of collapsed dam caused by earthquake, flood, and landslides has to be well considered. High quality standard of design, construction, monitoring and expertise [1-3] must be fulfilled to minimize the possible risk. Therefore, this study was carried out to evaluate the safety rank of 45 dams across Java (Appendix A) by using the total risk index tool (RIT). RIT comprised on-site inspections, evaluation results of instrumentation monitoring, and slope stability analyses

[4-5]. RIT could be used in prioritizing of maintenance, repair and evaluation of embankment dams that have limitations on instrumentation, as-built conditions, and performance history. The outcome of this study is to assist the designers, consultants, contractors, and dam managers in carrying out the tasks of inspection and evaluation of dam safety. It is also as an input to the central government and the regional government in setting up the priority rank of budget for maintenance, repair and evaluation of dams.

METHODOLOGY

This study consisted of data inventory, site inspection and computation works (Fig. 1). The outline methodology for risk indexing tool was developed from Andersen *et al.* [6-8], Balai Keamanan Bendungan, Ditjen Sumber Daya Air [9] and Chugh [10].

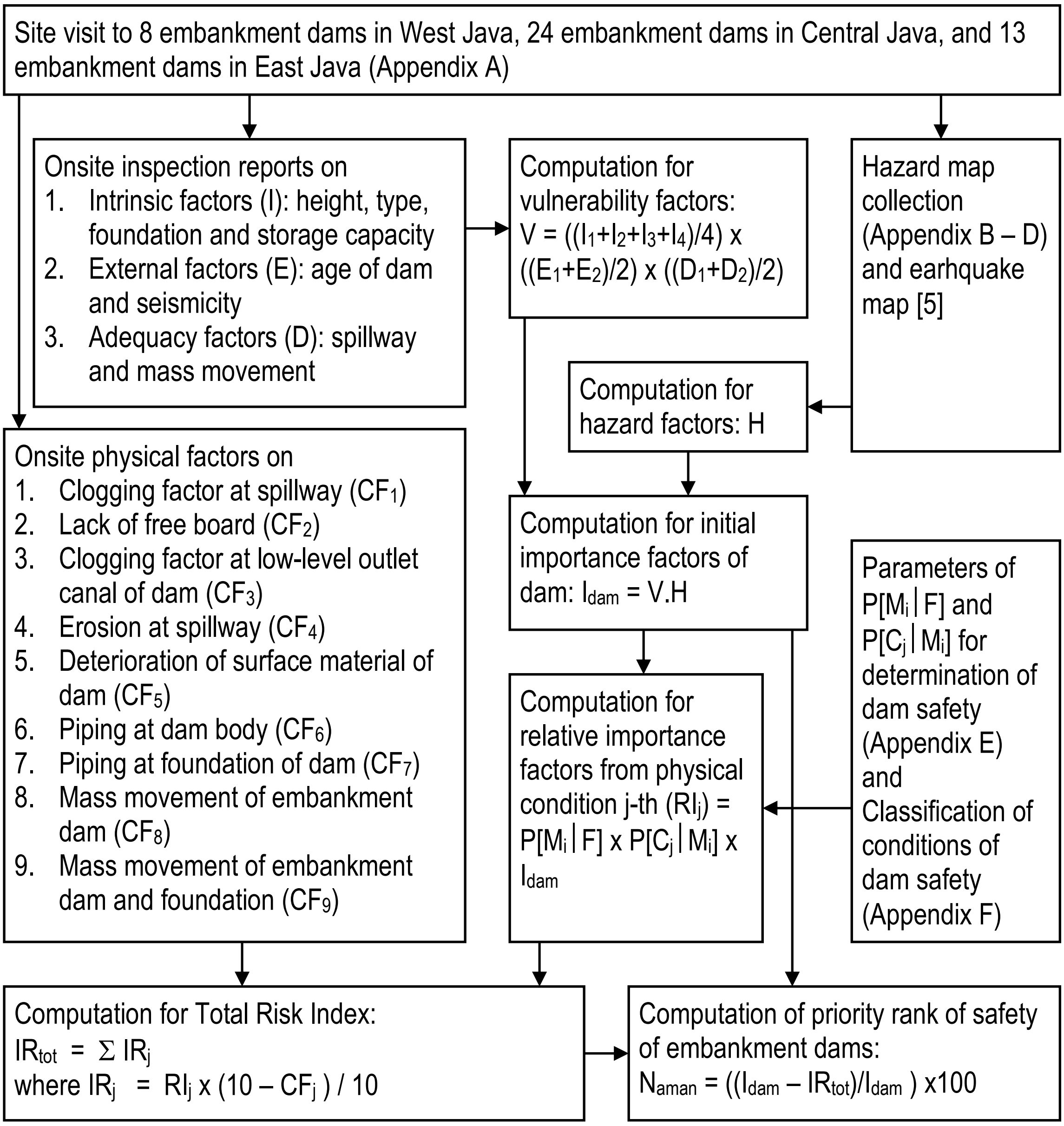

Fig. 1: Outline methodology for risk indexing tool.

Intrinsic, external and adequacy factors were collected by geotechnical instrumentation, dynamic parameters and seismicity. Evaluation of the results of geotechnical instrumentation monitoring since the observation year by making contours of pore water pressures at dam body and foundation, and by drawing characteristic changes of relationship between the pressure head and the reservoir water surface. Slope stability analyses of embankment dams under dynamic loading in steady seepage condition for return periods of more than 100 years [5]. These data were treated to obtain vulnerability factors. Computation of hazard factor was provided by using nature hazard vulnerability map scenario II (Appendix B – D). Both vulnerability and hazard factors were data in computing initial importance factors of dam: I_{dam}.

Relative importance factor of dam (RI) was calculated by using empirical study by USCOLD [11]. The parameters of $P[M_i|F]$ and $P[C_j|M_i]$ were very difficult to be obtained, because of limited data of dam failures in Indonesia. Parameters of $P[M_i|F]$ and $P[C_j|M_i]$ were used to evaluate the priority rank of dam safety in Java Island shown in Appendix E; and the criteria of safety condition classification of dams, see Appendix F.

There are many kinds of physical parameters of embankment dam that influenced by the dam failures. Nine potential factors which caused the failures were determined from the probability as initiating event in a series of event due to the failures. The results of inspection and data collecting which are needed for the analyses are all of technical design data from 8 dams in West Java (2006), 24 dams in Central Java (2003 and 2004), and 13 dams in East Java (2005).

All the above input data were used to calculate the total risk index and priority rank of safety of embankment dams. Dam safety rank (N_{aman}) was classified into satisfied for $N_{aman} \geq 75$ and not satisfied for $N_{aman} < 54$.

RESULTS AND DISCUSSION

Evaluation of Dam Safety Rank in West Java, 2006

Results of dam safety rank for embankment dams in West Java were summarized in Table 1. Pongkor and Cirata dams have an initial important factor (I_{dam}) of first and second rank that means their risks were very high if occuring failure. Results of on-site inspection showed that the cause of decreasing value of dam safety were influenzed by piping at dam body and foundation.

Table 1: Embankment dams safety rank in West Java

Number appears in a map (Appendix B)	Name of dam	I_{dam}	IR_{tot}	N_{aman}
1	Pongkor	1080.0	278.5	74.3
2	Saguling	625.0	138.8	77.8
3	Cirata	1000.0	222.0	77.8
4	Juanda (Jatiluhur)	750.0	161.8	78.4
5	Cileunca	525.0	133.7	74.6
6	Cipanunjang	675.0	166.5	75.3
7	Darma	315.0	101.5	67.8
8	Situpatok	540.0	138.3	74.4

Based on N_{aman} of less than 75, dams having enough classification were Pongkor, Cileunca, Darma and Situpatok. Preventive measure was based on I_{dam} and IR_{tot} by which Darma requires strengthening slope stability to prevent deformation 25-30 cm in downstream side of the dam.

Pongkor, Cileunca and Situpatok require strengthening slope stability to prevent deformation in upstream side of the dam.

Evaluation of Dam Safety Rank in Central Java, 2004

Results of dam safety rank for embankment dams in Central Java were summarized in Table 2. Wadaslintang and Sempor dams have an initial important factor (I_{dam}) of first and second rank that requires special measures against failure. Result of on-site inspection shows that the cause of decreasing value of dam safety were due to wet area in downstream slope surface (or high phreatic line), causing piping and unstability of slope. Besides, the seepage occured at the interface between outlet tunnel and tower, and at the dam body and foundation of spillway have to be considered. All of the phenomenon could influence the stability condition of downstream slope and foundation of dam.

Table 2: Embankment dams safety rank in Central Java

Number appears in a map (Appendix C)	Name of dam	I_{dam}	IR_{tot}	N_{aman}
9	Malahayu	540.0	105.5	80.5
10	Cacaban	337.5	134.2	60.2
11	Penjalin	540.0	95.3	82.4
12	Mrica	437.5	59.9	86.3
13	Garung	-	-	-
14	Sempor	630.0	68.1	89.2
15	Wadaslintang	875.0	115.1	86.9
16	Pejengkolan	-	-	-
17	Klego	240.0	42.1	82.4
18	Kedung Ombo	437.5	102.6	76.6
19	Greneng	48.0	13.9	71.1
20	Nglangon	240.0	50.3	79.0
21	Tempuran	54.0	14.6	72.9
22	Lodan Wetan	540.0	389.1	27.9
23	Gunung Rowo	135.0	29.7	78.0
24	Gembong	105.0	37.8	64.0
25	Sermo	472.0	49.6	89.5
26	Nawangan	420.0	88.2	79.0
27	Ngancar	255.0	42.3	83.4
28	Song Putri	360.0	72.0	80.0
29	Plumbon	250.0	79.1	68.4
30	Parangjoho	472.5	58.5	87.6
31	Wonogiri	367.5	55.7	84.9
32	Krisak	-	-	-
33	Cengklik	240.0	51.0	78.8
34	Delingan	270.0	44.2	83.6
35	Ketro	420.0	97.3	76.8

Based on N_{aman} of less than 75, dam having not enough classification was Cacaban. On-site inspection showed that wet area at the surface of downstream slope (high phreatic line) caused seepage at the interface between outlet tunnel and tower, and seepage at the body and foundation of spillway. Preventive measure was based on I_{dam} and IR_{tot} by which Cacaban requires strengthening slope stability to prevent deformation in downstream side of the dam. However, special attention was given to Tempuran, Kedung Ombo and Plumbon. The three dams require preventive measures against soil erosion and animal holes at the dam crest.

Evaluation of Dam Safety Rank in East Java, 2005

Results of dam safety rank for embankment dams in East Java were summarized in Table 3. Based on N_{aman} of less than 75, dams having enough classification and not enough classification were Prijetan, Selorejo and Notopuro. Measures for Prijetan and Selorejo dams have to confirm when the dams are operated normally. Notopuro was the worst safety conditions that need more detailed investigation for improvement method of the dam.

Table 3: Embankment dams safety rank in East Java

Number appears in a map (Appendix D)	Name of dam	I_{dam}	IR_{tot}	N_{aman}
36	Pacal	210.0	63.5	69.8
37	Prijetan	135.0	38.6	71.4
38	Gondang	270.0	65.5	75.7
40	Pondok	367.5	55.6	84.9
41	Selorejo	775.0	232.7	70.0
42	Sengguruh	367.0	83.8	77.2
43	Wlingi	510.0	102.5	79.9
44	Lahor	625.0	134.0	78.6
45	Sutami	625.0	147.8	76.4
46	Wonorejo	620.0	127.4	79.5
47	Bening	405.0	79.0	80.5
49	Sangiran	340.0	74.2	78.2
50	Notopuro	240.0	106.6	55.6

CONCLUSIONS

A risk indexing tool was applied to rank safety for embankment dams that were little or no instrumentations, limited or no information on as-built conditions, and little or no information on the performance history. The tool was accompanied with on-site inspection to investigate validity of the tool. This study proposed preventive measures against failure were slope stability in upstream or downstream of dams. Therefore, the highest priority for conducting monitoring, maintenance, and mitigation are addressed to physical environmental conditions of the dams.

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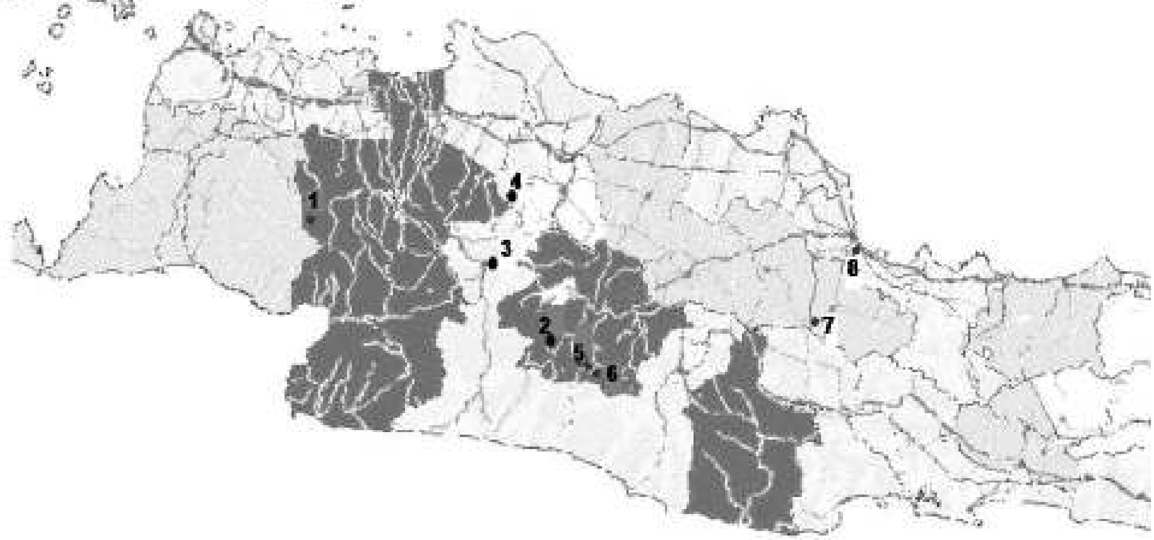
References

1. Departemen Pekerjaan Umum, 2000. Tata Cara Pengendalian Mutu Bendungan Urugan, Pd.T -17-2000-03, Kep Men Pekerjaan Umum No: 08/KPTS/T/2000.
2. Najoan, Th.F. dan Soetjiono Carlina, 2002. Desain Tubuh Bendungan Tipe Urugan. Seri Bangunan Air, Pusat Penelitian dan Pengembangan Sumber Daya Air 2002, ISBN 979-3197-17-X.
3. Najoan, Th.F. dan Soetjiono Carlina, 2002. Metode Analisis dan Cara Pengendalian Rembesan untuk Bendungan Tipe Urugan. Seri Bangunan Air, Pusat Penelitian dan Pengembangan Sumber Daya Air 2002, ISBN 979-3197-20-X.
4. Najoan, Th.F. dan Soetjiono Carlina, 2002. Metode Analisis Stabilitas Lereng Statik Bendungan Tipe Urugan. Seri Bangunan Air, Pusat Penelitian dan Pengembangan Sumber Daya Air 2002, ISBN 979-3197-18-8.
5. Najoan, Th.F, 2002. Penentuan Beban Gempa pada Bangunan Pengairan. Seri Bangunan Air, Pusat Penelitian dan Pengembangan Sumber Daya Air 2002, ISBN 979-3197-19-6.
6. Andersen, G.R., Chouinard, L.E., Bouvier, C.J. and W.E. Back, 1999. Ranking Procedure on Maintenance Tasks for Monitoring of Embankment Dams. Journal of Geotechnology and Geoenvironmental Engineering, 125 (4): 247-259.
7. Andersen, G.R., Chouinard, L.E., Hover, W.H. and C.W. Cox, 2001. Risk Indexing Tool to Assist in Prioritizing Improvements To Embankment Dam Inventories. Journal of Geotechnology and Geoenvironmental Engineering, 127 (4): 325-334.
8. Andersen, G.R., Cox, C.W, Chouinard, L.E., and W.H. Hover, 2001. Prioritization of Ten Embankment Dams According to Physical Deficiencies. Journal of Geotechnology and Geoenvironmental Engineering, 127 (4): 335-345.
9. Balai Keamanan Bendungan, Ditjen Sumber Daya Air, 2003. Pedoman Inspeksi Keamanan Bendungan, Januari 2003.
10. Chugh, A. K., 1990. Evaluation of Embankment Dam Stability. A report prepared for training aids for dam safety program, Geotechnical Engineering and Geology Division, Bureau of Reclamation –Engineering and Research, Denver, Colorado USA, July 1990.
11. USCOLD Subcommittee of Dam Incidents and Accidents, 1988. Lessons from Dam Incidents", USA-II ASCE, New-York.
12. Puslitbang Sumber Daya Air, 2002. Pengembangan Peta Rawan Bencana Alam Gempa Bumi untuk Indonesia. Laporan Penelitian no 02/P2TP&SP/02.

Appendix A: List of embankment dams in the study area of Java

No.	Name of dams	Province	River Region Unit	Type
1	Pongkor	West Java	Cisadane-Ciliwung	Homogeneous earthfill
2	Saguling	West Java	Citarum	Rockfill with core
3	Cirata	West Java	Citarum	Rockfill with membrane
4	Juanda (Jatiluhur)	West Java	Citarum	Rockfill with core
5	Cileunca	West Java	Citarum	Homogeneous earthfill
6	Cipanunjang	West Java	Citarum	Homogeneous earthfill
7	Darma	West Java	Cimanuk	Rockfill with membrane
8	Situpatok	West Java	Cimanuk	Homogeneous earthfill
9	Malahayu	Central Java	Pemali Comal	Non-homogeneous earthfill
10	Cacaban	Central Java	Pemali Comal	Homogeneous earthfill
11	Penjalin	Central Java	Pemali Comal	Homogeneous earthfill
12	Mrica	Central Java	Serayu-Bogowonto	Rockfill with core
14	Sempor	Central Java	Serayu-Bogowonto	Rockfill with core
15	Wadaslintang	Central Java	Serayu-Bogowonto	Rockfill with core
17	Klego	Central Java	Jratun Seluna	Homogeneous earthfill
18	Kedung Ombo	Central Java	Jratun Seluna	Rockfill with core
19	Greneng	Central Java	Jratun Seluna	Homogeneous earthfill
20	Nglangon	Central Java	Jratun Seluna	Homogeneous earthfill
21	Tempuran	Central Java	Jratun Seluna	Homogeneous earthfill
22	Lodan Wetan	Central Java	Jratun Seluna	Homogeneous earthfill
23	Gunung Rowo	Central Java	Jratun Seluna	Homogeneous earthfill
24	Gembong	Central Java	Jratun Seluna	Rockfill with core
25	Sermo	Central Java	Progo-Opak-Oyo	Rockfill with core
26	Nawangan	Central Java	Bengawan Solo	Homogeneous earthfill
27	Ngancar	Central Java	Bengawan Solo	Rockfill with core
28	Song Putri	Central Java	Bengawan Solo	Rockfill with core
29	Plumbon	Central Java	Bengawan Solo	Homogeneous earthfill
30	Parangjoho	Central Java	Bengawan Solo	Non-homogeneous earthfill
31	Wonogiri	Central Java	Bengawan Solo	Rockfill with core
33	Cengklik	Central Java	Bengawan Solo	Homogeneous earthfill
34	Delingan	Central Java	Bengawan Solo	Homogeneous earthfill
35	Ketro	Central Java	Bengawan Solo	Rockfill with core-composite
36	Pacal	East Java	Bengawan Solo	Rockfill with membrane
37	Prijetan	East Java	Bengawan Solo	Homogeneous earthfill
38	Gondang	East Java	Bengawan Solo	Homogeneous earthfill
40	Pondok	East Java	Bengawan Solo	Rockfill with core
41	Selorejo	East Java	Brantas	Homogeneous earthfill
42	Sengguruh	East Java	Brantas	Rockfill with core
43	Wlingi	East Java	Brantas	Rockfill with core
44	Lahor	East Java	Brantas	Rockfill with core
45	Sutami	East Java	Brantas	Rockfill with core
46	Wonorejo	East Java	Brantas	Rockfill with core
47	Bening	East Java	Brantas	Homogeneous earthfill
50	Sangiran	East Java	Bengawan Solo	Rockfill with core
51	Notopuro	East Java	Bengawan Solo	Homogeneous earthfill

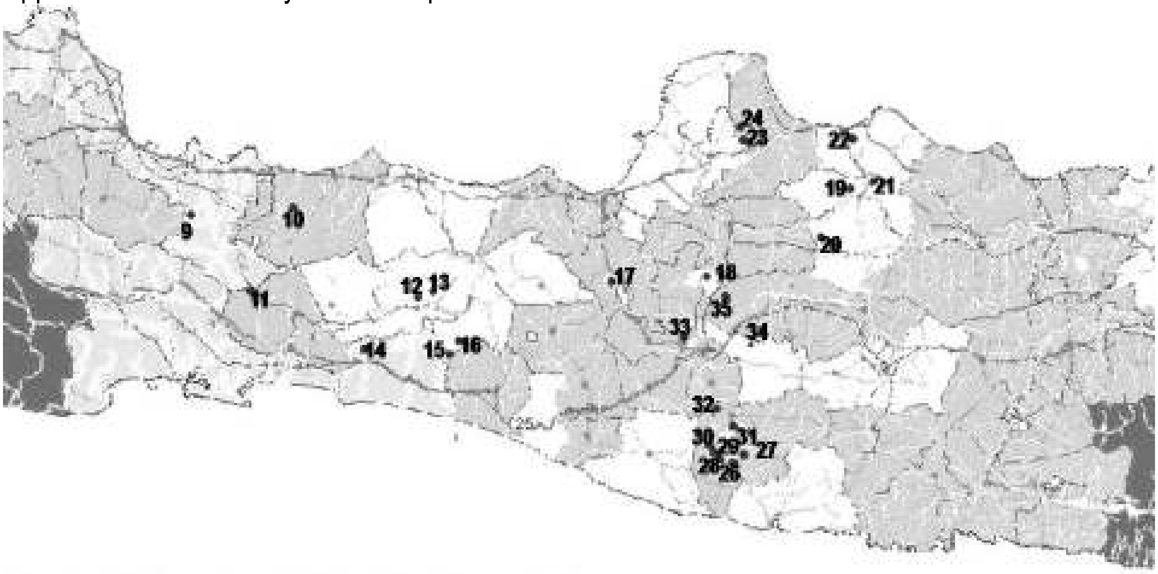
Appendix B: Vulnerability hazard map of West Java and dams location



Dams in the highest hazard area: Pongkor (1), Saguling (2), Cileunca (5) and Cipanunjang (6).
Dams in a high hazard area: Cirata (3), Juanda Jatiluhur (4) and Situpatok (8).
Dam in a medium hazard area: Darma (7).

Reference:
Puslitbang Sumber Daya Air, 2002. Pengembangan Peta Rawan Bencana Alam Gempa Bumi untuk Indonesia. Laporan Penelitian no 02/P2TP&SP/02.

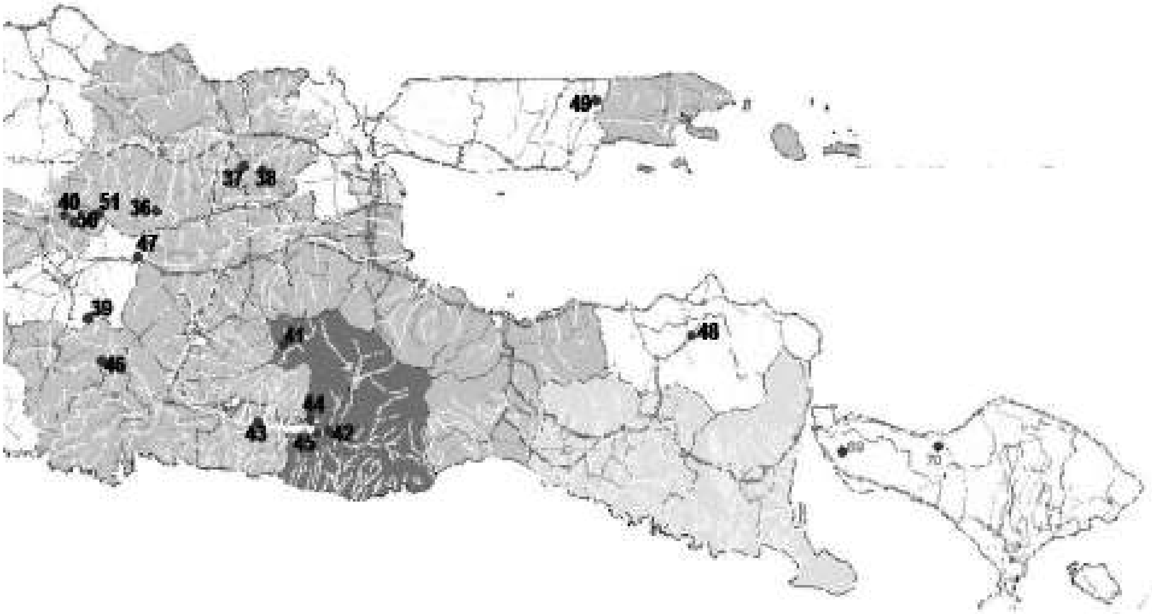
Appendix C: Vulnerability hazard map of Central Java and dams location



Dams in a high hazard area: Malahayu (9) and Sempor (14).
Dams in a medium hazard area: Cacaban (10), Penjalin (11), Klego (17), Kedung Ombo (18), Gunung Rowo (23), Gembong (24), Nawangan (26), Ngancar (27), Song Putri (28), Plumbon (29), Parangjoho (30), Wonogiri (31), Krisak (32), Cangkik (33) and Ketro (35).
Dams in a low hazard area: Mrica (12), Garung (13), Wadaslintang (15), Pejengkolan (16), Greneng (19), Nglangon (20), Tempuran (21), Lodan Wetan (22) and Sermo (25).

Reference:
Puslitbang Sumber Daya Air, 2002. Pengembangan Peta Rawan Bencana Alam Gempa Bumi untuk Indonesia. Laporan Penelitian no 02/P2TP&SP/02.

Appendix D: Vulnerability hazard map of East Java and dams location



Dams in the highest hazard area: Selorejo (41), Sengguruh (42), Lahor (44), Sutami (45).
Dams in a medium hazard area: Pacal (36), Prijetan (37), Gondang (38), Pondok (40), Wingi (43), Wonorejo (46), Sangiran (50), Notopuro (51).
Dams in a low hazard area: Tlogo Ngebel (39), Bening (47), Sampean Baru (48), Klampis (49).

Reference:
Puslitbang Sumber Daya Air, 2002. Pengembangan Peta Rawan Bencana Alam Gempa Bumi untuk Indonesia. Laporan Penelitian no 02/P2TP&SP/02.

Appendix E: Parameters of $P[M_i \mid F]$ and $P[C_j \mid M_i]$ for determination of dam safety

No	Failure modes	Probability of failure modes $P[M_i \mid F]$	Description of physical failure	Probability of physical condition $P[C_j \mid M_i]$	Relative importance factor RI_j
1	Overtopping (1)	0.49	Clogging at spillway canal (1)	0.3	$0.49 \times 0.3 \times I_{dam}$
			Lackng of free board (2)	0.1	$0.49 \times 0.1 \times I_{dam}$
			Clogging at outlet canal (3)	0.6	$0.49 \times 0.6 \times I_{dam}$
2	Surface erosion (2)	0.09	Erosion at spillway canal (4)	0.7	$0.09 \times 0.7 \times I_{dam}$
			Deterioration of surface protection material (5)	0.3	$0.09 \times 0.3 \times I_{dam}$
3	Piping (3)	0.32	Piping at the dam body (6)	0.7	$0.32 \times 0.7 \times I_{dam}$
			Piping at the foundation (7)	0.3	$0.32 \times 0.3 \times I_{dam}$
4	Mass movement (4)	0.10	Mass movement at the dam body (8)	0.5	$0.10 \times 0.5 \times I_{dam}$
			Mass movement at the dam body and foundation (9)	0.5	$0.10 \times 0.5 \times I_{dam}$

Appendix F: Classification of conditions of dam safety [8]

No.	Value of safety (N_{aman})	Classification	Criteria		Actions to be needed
			Normal loads condition	Extra-ordinary loads condition	
1	> 75	Satisfied	Stable	Stable to extreme flood and earthquake	No action needed.
2	65 – 75	Enough	Stable	Possible not stable to extreme flood and earthquake	More analyses are needed to prove that the dam can be operated normally.
3	55 – 64	Not enough	Stable	Not stable enough to extreme flood and earthquake. Possible deterioration material quality.	More studies and investigation are needed to obtain new design parameter, install instruments for observing the behavior of the dam. The dam can be operated normally, but should be carefully inspected for deficiencies.
4	< 54	Not good/ unsatisfied	Not stable	Not stable	Actions are urgently needed to solve the problem. Dam operation should be stopped or limited. Action to repair immediately should be done.