FAILURES AND INCIDENTS AT SWEDISH TAILINGS DAMS – EXPERIENCES AND COMPARISONS

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1. INTRODUCTION

Tailings dams are necessary for efficient mineral and metal production and need therefore to be constructed, operated, maintained and closed in a safe and acceptable manner. In this context “safe and acceptable” means a level agreed upon by all stakeholders. It is prudent to assess the causes of past incidents and failures, learn from the experiences and apply this knowledge to current and future operations (Strachan 2002). Trial and error have been used to improve and develop technology throughout history, but to learn from the experience and make use of the knowledge is today often underestimated or forgotten. This paper therefore intends to improve the knowledge of tailings dams safety by investigating the history of events (failures, incidents and event driven maintenance) at Swedish tailings dams. This will be of value not only for Swedish and international mining companies, but also for the county administration, consultants and contractors working within Sweden as well as internationally.

In order to be able to analyse and compare the data, some terms need to be defined and/or described, which will constitute the first part of this paper while the second part deals with the analysis of statistical material.

2. DEFINITIONS

The definitions below of dam (i.e. tailings dam), failure, incident and event driven maintenance are from Bjelkevik (2005) and reproduced.

The need to define tailings dam is due to the differences between tailings dams and conventional water retention dams (WRD). A WRD is designed and constructed to store water for the purpose of irrigation, hydropower etc., while tailings dams, on the other hand, are designed and constructed to store tailings. Tailings dams are normally raised either in stages or continuously as the impoundment is filled with tailings. Depending on the characteristics of the tailings and the mining process the amount of water stored together with the tailings differ.

Definitions;

- *Tailings dam* is a structure designed to settle and keep tailings and process water. (European Commission, 2004)

- *Tailings dam failure* is an event resulting in the tailings dam structure failing to retain what it is designed and constructed to retain, causing an emergency situation due to the spill of tailings and/or water. Consequences can be human, environmental, economical or cultural.

- *Incident* is an unexpected event that happens to a tailings dam that poses a threat to the over all dam safety and needs response quickly to avoid a likely dam failure.

- *Event driven maintenance* is an event that could have been expected, but is not included in the normal operation of the tailings dam and require measures to be taken in order to prevent further development of the event and/or to lower the risk associated with the event.

3. METHOD

To evaluate events that have occurred at Swedish tailings dams and draw useful conclusions from these, accessible data has been collected and analysed. Data have been collected from the dam owners, from files and archives at Sweco VBB AB[1] and from Raw Materials Data (RMD, 2005). These sources will in the view of the author, encompass the majority of documented events. The compilation is not complete and the author is convinced events are lost, especially in a historical perspective. The reason for this is that information has been lost due to mines changing owners and/or closing down and that historically this information was not of interest. However, it is assumed that the data for failures are complete for the last 15 year period when reporting has become focus. The author believes, that missing data might be important, but even so, conclusions and priorities can be drawn from the presented material to help future dam safety work.

The compilation consists of 58 events from 1944 to 2004 at Swedish tailings dams. Most facilities are in operation, some are remediated but are still of the responsibility of an active mining company. No events from closed down mines where no company is responsible are included in the data analyzed here.

To facilitate an international comparison, the system of categorising events used here is developed on the basis of the systems in ICOLD (2001) and ICOLD (1996).

[1] Sweco VBB AB is a Swedish consultant company that has been the main consultant involved with Swedish tailings dams since around 1960.

4. SWEDISH TAILINGS DAMS

In total 58 events have been found and categorized in terms of dam type, dam height, event type, event cause etc.

Event type follows the categories in ICOLD (2001) except for the addition of "event driven maintenance" and the removal of "groundwater";

- Failure of a Tailings Dam
- Incident at a Tailings Dam
- Event Driven Maintenance at a Tailings Dam

Definitions of these categories are given above under "Definitions".

To normalise events they have been given a value according to the seriousness of the event, where;

Failure	=	3
Incident	=	2
Event driven maintenance	=	1

Dam type follows the classification of categories in ICOLD (1996) with the exception of type D and E4;

A Conventional Dam Embankment of borrow material
B Staged Conventional Embankment of borrow material
D Homogeneous draining embankment barrier of waste rock
E2 Embankment with Tailings in Structural Zone, centreline construction
E4 Embankment with Tailings in Structural Zone, upstream construction by placing tailings mechanically
NA Not applicable
NR Not reported

In the compilation of incidents and failures in ICOLD (2001) other categories are used.

Dam height is given in meters, as the highest dam height. This is not necessarily the height of the dam in the position of the event.

Initiating cause follows the categories in ICOLD (2001) with minor changes;

OP *Operational* is an event caused by man, for example deposition malfunction, operating water level, improper maintenance work etc.
L *Leakage* is an event where "natural" or "normal" seepage increases to become leakage and an event requiring action.
W *Water situation* is an event where the level of impounded water or tailings slurry increases to a level resulting in dam safety problems, with the extreme case equal to overtopping.
ST *Structural* is an event caused by malfunction, faults and/or deficiencies in design or construction of the dam, foundation or associated structures.
ED *External defects* include phenomena like external erosion due to precipitation, waves, ice etc., cracks and settlements.
IER *Internal erosion* is an event of internal erosion in the dam body, often due to lack of proper filters, i.e. filters not fulfilling the filter requirements.
I *Ice and frost* are events induced by ice or frost actions. For example ice blocking decants or outlets or freezing and thawing destroying the compaction of the dam construction material, which in turn can lead to internal erosion. However, in some cases it can be difficult to identify that freezing and thawing actually caused the event.
U *Unknown* is an event where the cause is unknown.

Dam fill material follows the classification of categories in ICOLD (1996) with the addition of type E/R, E/T and C/R;

E/R Earth and rock fill
E Earth fill
R Rock fill
T Tailings
E/T Earth and tailing
C/R Concrete and rock fill
NA Not applicable

Results will be presented in diagrams below, which will be discussed in the following section, 5 Discussion.

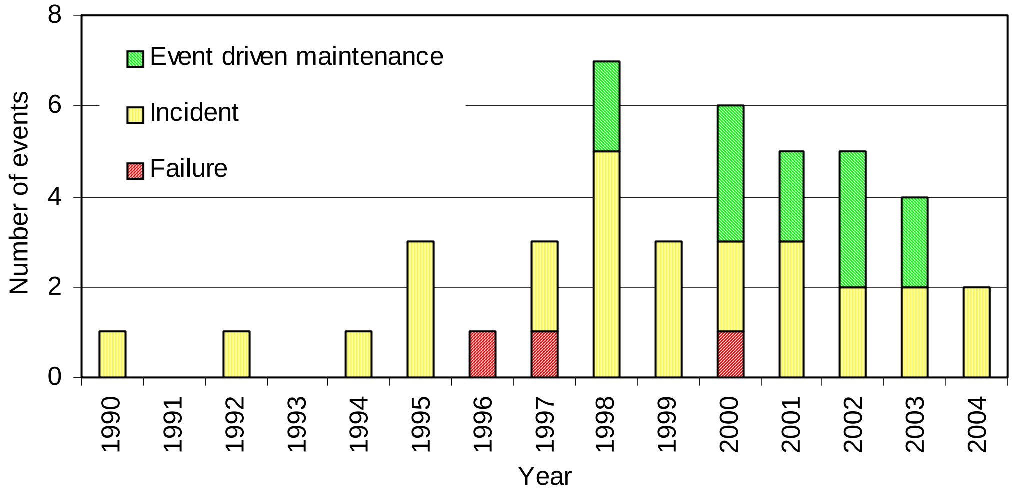

Figure 1 Number of failures, incidents and event driven maintenance per year from 1990 to 2004. (Bjelkevik 2005)

Nombre de ruptures, incidents et entretien événementiel par année, de 1990 à 2004, (Bjelkevik 2005)

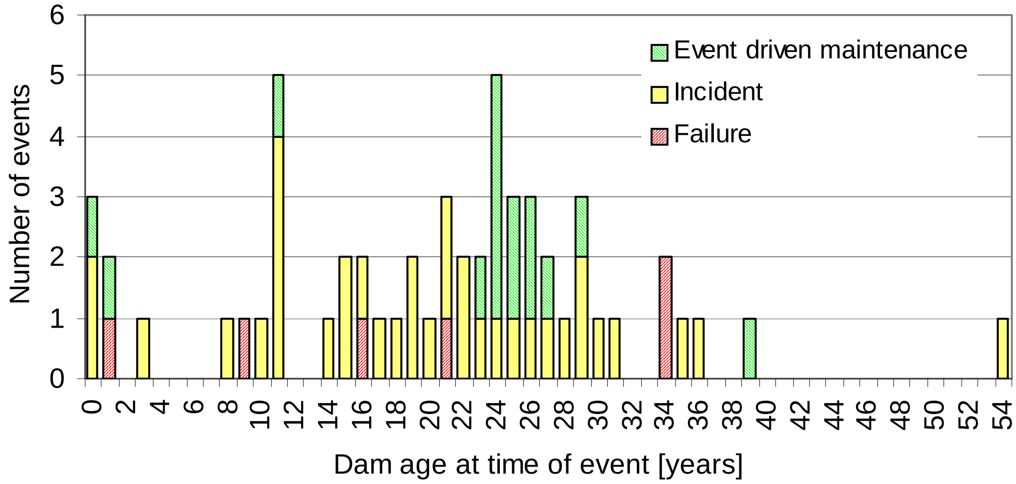

Figure 2 Number of failures, incidents and event driven maintenance compared to dam age at time of event.

Nombre de ruptures, incidents et entretien événementiel en comparaison de l'age de la digue au moment de l'événement.

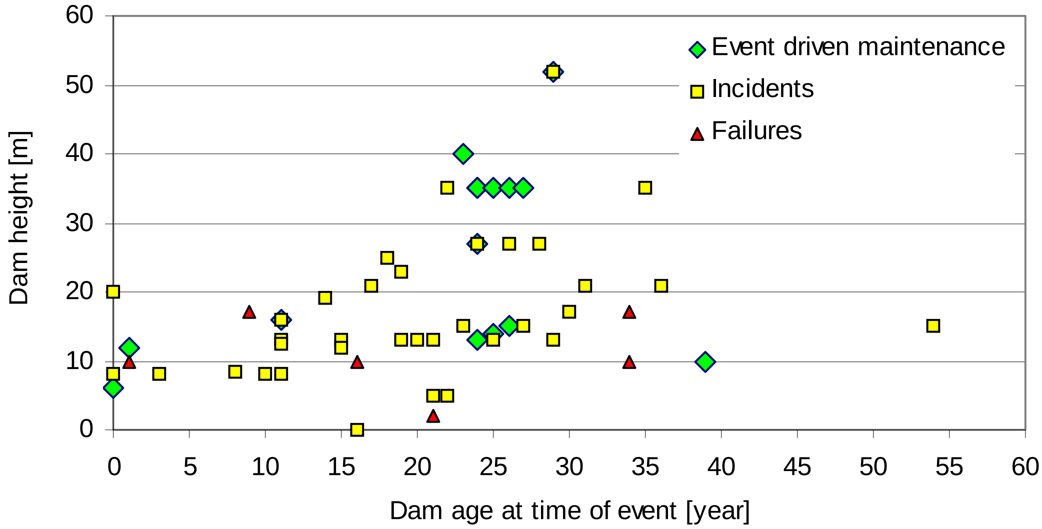

Figure 3 Dam height compared to dam age at time of event.

La hauteur de la digue en comparaison de son age au moment de l'événement.

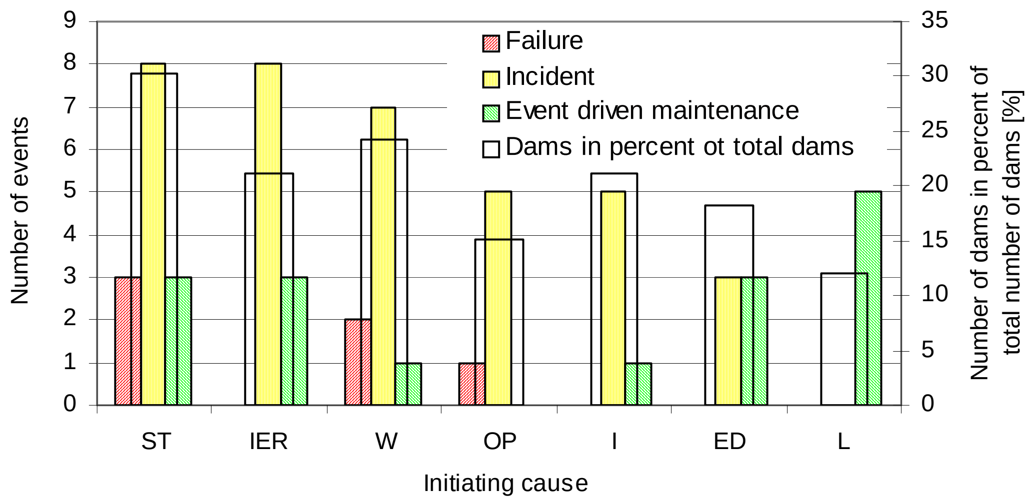

Figure 4 Number of failures, incidents and event driven maintenance compared to initiating cause as well as number of dams exposed to an event in percent of total number of dams exposed to events.

Nombre de ruptures, incidents et entretien événementiel en comparaison de la cause déclencheur et le nombre de digues ayant été exposé à un événement, en pourcentage de la totale des digues exposé aux événements.

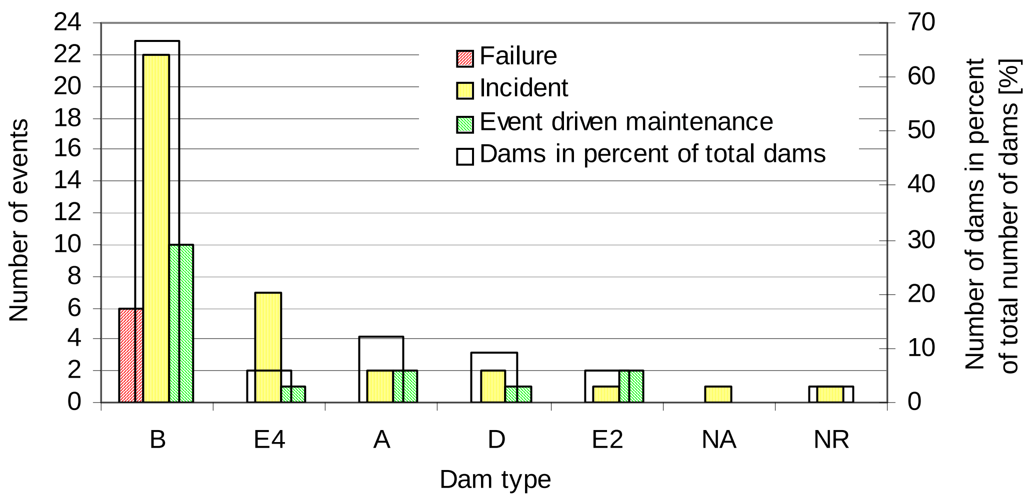

Figure 5 Number of failures, incidents and event driven maintenance compared to dam type as well as number of dams exposed to an event in percent of total number of dams exposed to events.

Nombre de ruptures, incidents et entretien événementiel en comparaison du type de digue et le nombre de digues ayant été exposé à un événement, en pourcentage de la totale des digues exposé aux événements.

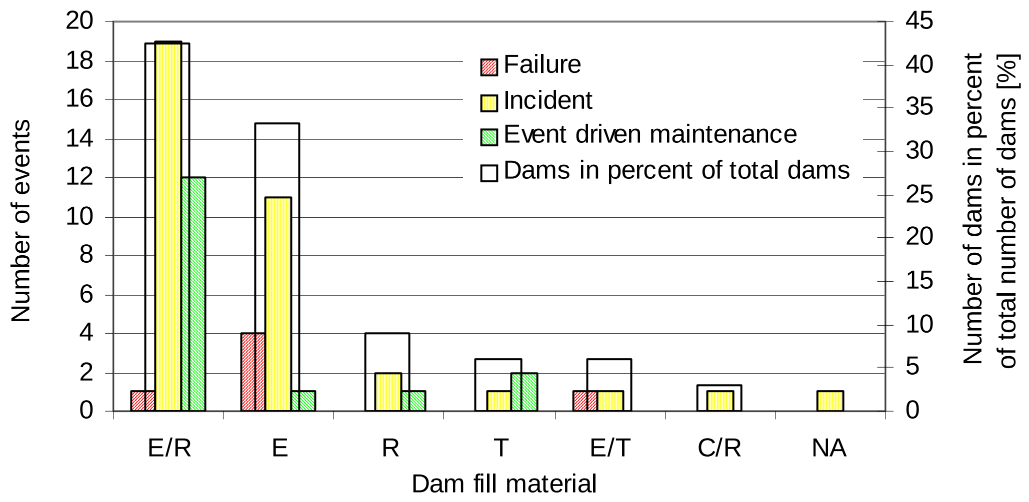

Figure 6 Number of failures, incidents and event driven maintenance compared to dam fill material as well as number of dams exposed to an event in percent of total number of dams exposed to events.

Nombre de ruptures, incidents et entretien événementiel en comparaison du matériau de remplissage des digues et le nombre de digues ayant été exposé à un événement, en pourcentage de la totale des digues exposés aux événements.

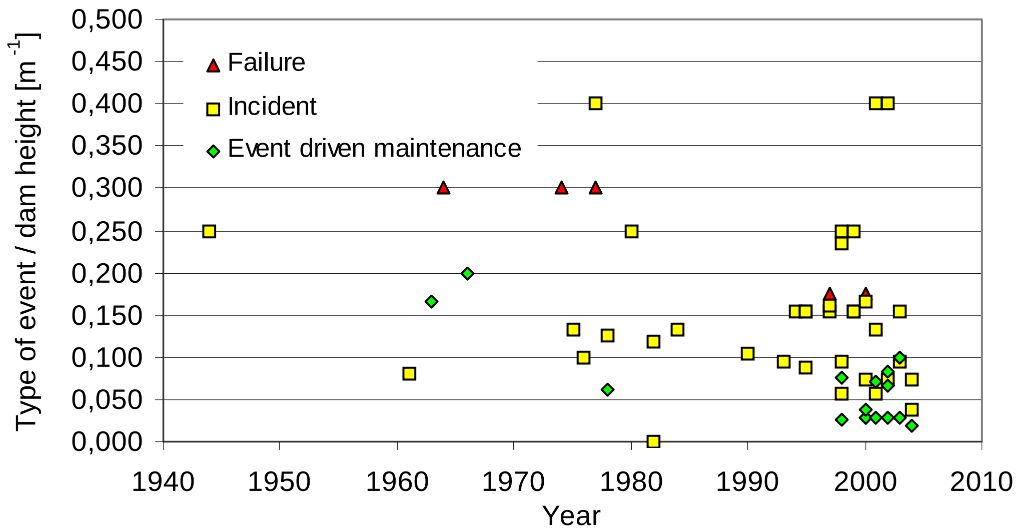

Figure 7 Event type (failure, incident or event driven maintenance) normalised against dam height plotted versus year of event.

Type d'événement (ruptures, incidents et entretien événementiel) normalisé contre la hauteur de la digue en fonction de l'année de l'événement.

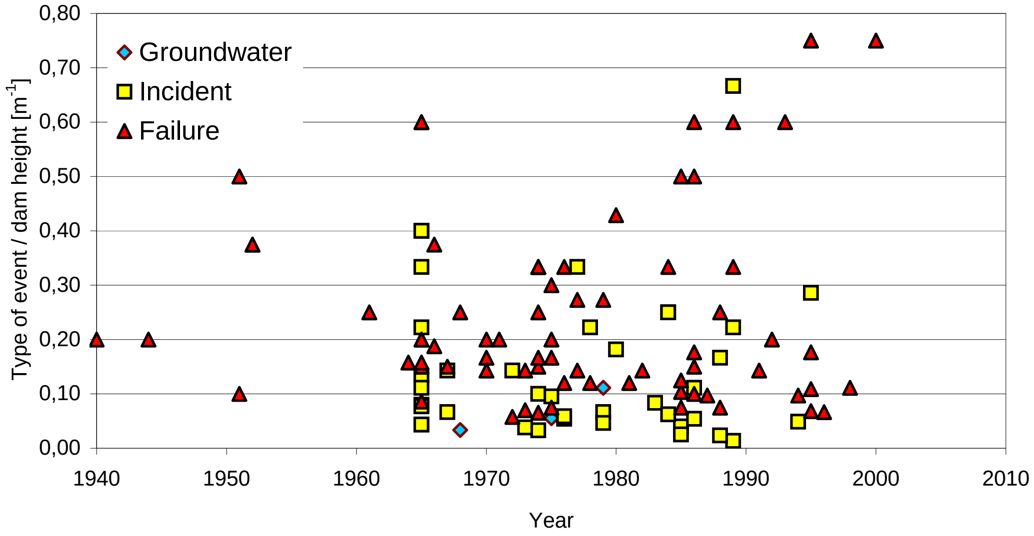

Figure 8 From the international statistics, i.e. ICOLD (2001), 119 events out of 221 (54%) have enough information (i.e. year, event type and dam height) to plot event type (failure, incident or groundwater) normalised against dam height against year of event.

Provenant des statistiques internationales, c.-à.-d. ICOLD (2001), 119 événements sur un totale de 221 (54%) ont assez d'information (c.-à.-d. année, type d'événement et la hauteur de la digue) pour tracer la courbe de type d'événement (rupture, incident ou eau de fond) en fonction la hauteur de la digue en fonction de l'année de l'événement.

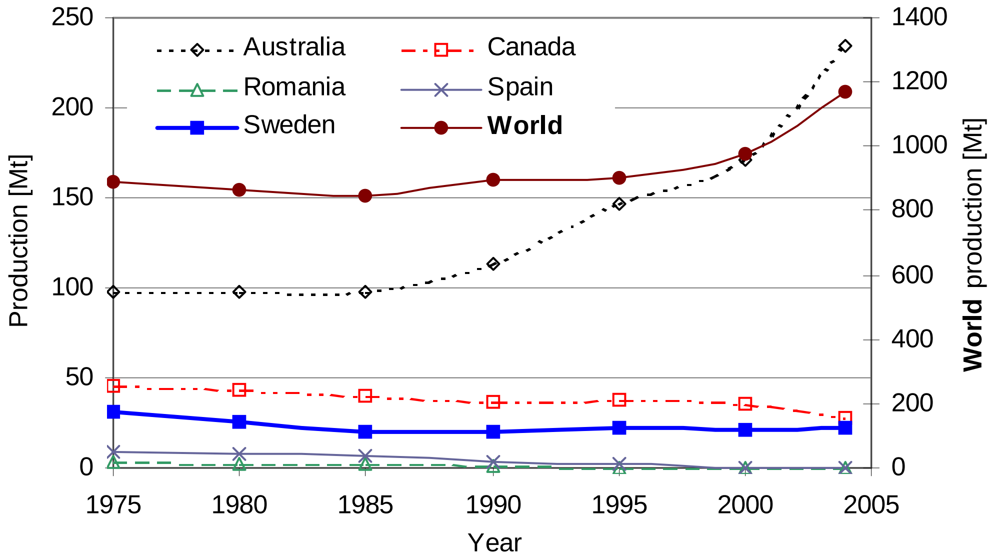

Figure 9 Iron ore mine production for some countries. (RMD, 2005).

La production minière de minerai de fer pour certains pays. (RMD, 2005).

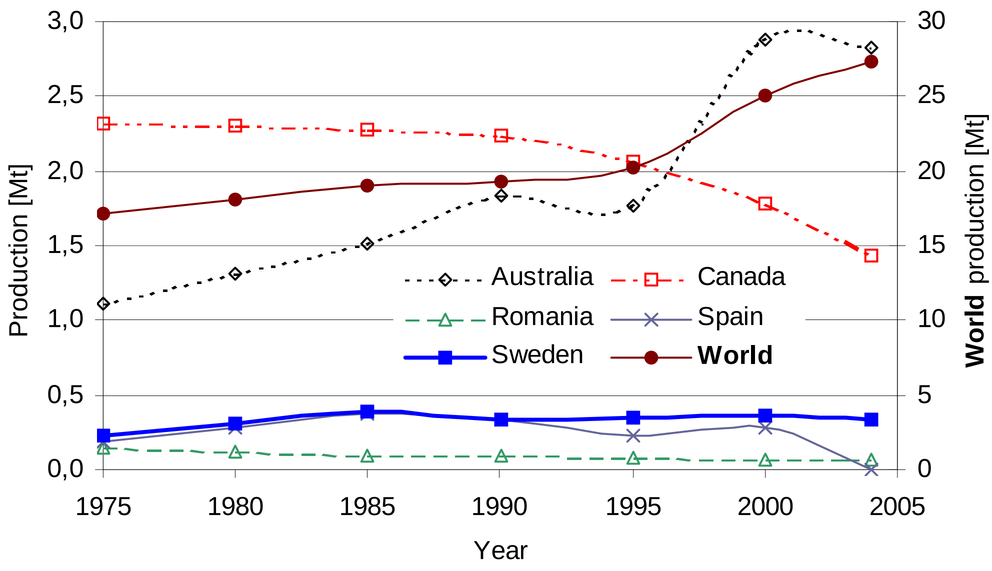

Figure 10 Non ferrous (copper, lead, silver, gold and zink) mine production for some countries. (RMD, 2005).

La production minière des métaux non-ferreux (cuivre, plomb, argent, or, zinc) pour certains pays. (RMD, 2005)

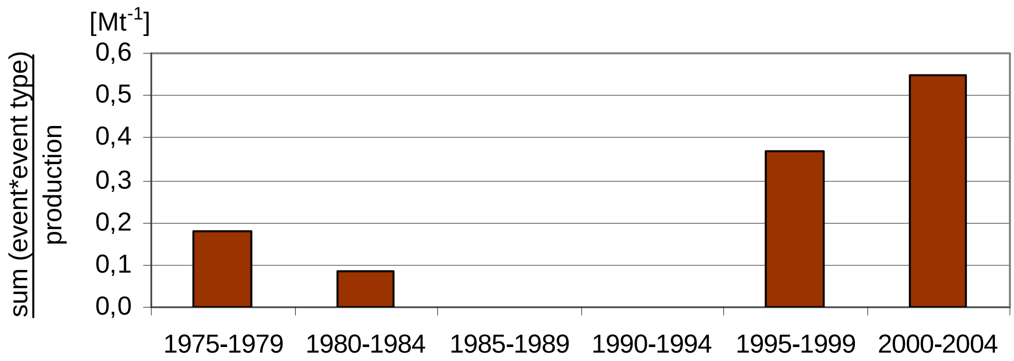

Figure 11 Events (failures, incidents and event driven maintenance) at ferrous tailings dams normalised against mine production in Sweden during five year periods.

Événements (ruptures, incidents, entretien événementiel) normalisé contre la production minière suédoise pendant des périodes de cinq ans.

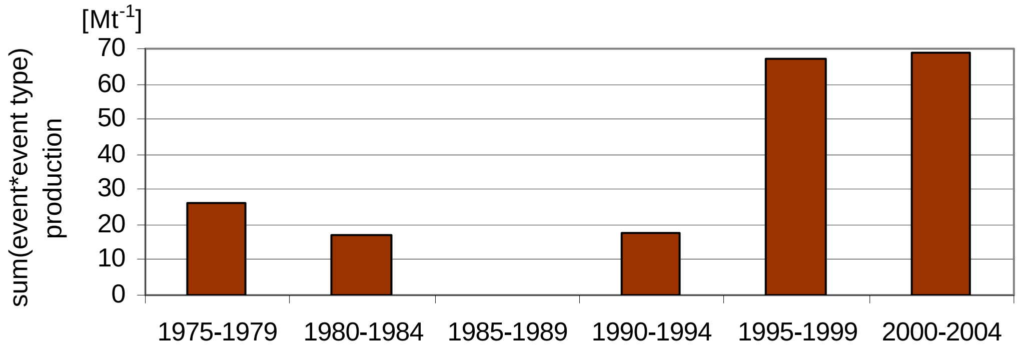

Figure 12 Events (failures, incidents and event driven maintenance) at non ferrous tailings dams normalised against mine production in Sweden during five year periods.

Événements (ruptures, incidents, entretien événementiel) aux digues à rejets non-ferreux normalisé contre la production minière suédoise pendant des périodes de cinq ans.

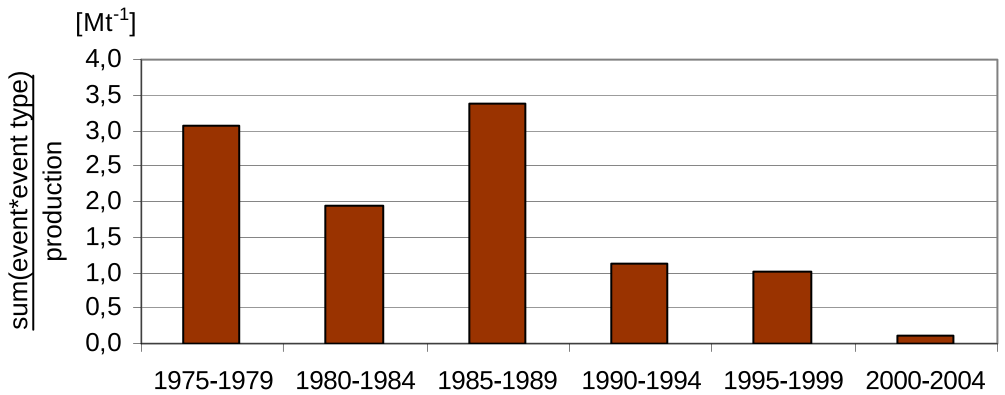

Figure 13 From the international statistics, i.e. ICOLD (2001), 79 events out of 221 (34%) are in the time span from 1975-2004 and have enough information (i.e. year and event type) to plot events (failures, incidents and groundwater) at non ferrous tailings dams normalised against world mine production. Information is given for periods of five years.

Provenant des statistiques internationales, c.-à.-d. ICOLD (2001), 79 événements sur un totale de 221 (34%) de la période 1975 à 2004 ont assez d'information (c.-à.-d. année et type d'événement) pour tracer la courbe de type d'événement (rupture, incident ou nappe phréatique) aux digues de rejets non ferreux normalisé contre la production minière mondiale. L'information est offert pour les périodes de cinq ans.

5. DISCUSSION

As pointed out earlier the compilation of events is not complete, at least not in a historical perspective. However, with regard to failures it can be assumed to be complete for the last 15 years. And further, with regard to all events, it is assumed to be complete during 2000 to 2004. The latter is due to good and established routines within the mining companies and due to the increased interest in tailings dam safety by the authorities.

A parameter being interesting to use in the analysis is the total number of tailings dams, and not just the tailings dams that have been reported for an event. This information has, however, not been possible to obtain. Especially not in a historical perspective and for recent years the number of remediated tailings dams is not known. The present analysis is therefore only based upon reported tailings dams.

Figure 1, from Bjelkevik (2005), shows the number of events at Swedish tailings dams during the last 15 years. It is already shown in Bjelkevik (2005) that the majority of events, or 70% of the events, for the last 60 year period occurred during this 15 year long time period. The major increase in reported events are in 1998, which probably is explained by the initiation of dam safety programs at most Swedish mine sites and that focus was moved from not just environmental issues but to environmental and dam safety issues. The two failures in Sweden in 1996 and 1997 and the failure in Spain in 1998 probably speeded up the change. Figure 1 also shows that the number of events is decreasing after 1998 and that the seriousness of the events have decreased during the same time period as well, i.e. event driven maintenance constitute a larger part of total number of events. This is believed to be due to the improved reporting routines.

In figure 2 the number of events have been plotted against the age of the dam at the time of the event. Incidents and failures seem to be spread out between a dam age of 0 and 40 years, while event driven maintenance events seem to be present mainly at tailings dams at the age of 24-26 years. This can be due to the fact that event driven maintenance is mainly reported during the last 15 years and tailings dams in operation during this time period are at that age. Therefore the information given in figure 2 seems to be what is expected.

It was hypothesized that the height of the dam was related to the seriousness or number of events. To analyze this, Figure 3 has been plotted. Two events, an incident and an event driven maintenance at a dam having an age of about 300 years, have been left out in order to give a clearer picture of the other events. Dam heights vary between 0-52 m, but failures are only present at dam heights between 0-20 m. Increasing dam height therefore does not seam to be related to increased seriousness or increased number of events, as was hypothesized by the author. The statistical data might, however, be too sparse to draw any firm conclusions about the impact of dam height. Incidents seem to be present at any dam height and dam age. As in the previous figure event driven maintenance does not seem to be related to dam height, but is mainly present at the dam age of 24-26 years.

The categories for initiating cause have in Figure 4 been changed slightly compared to event cause in Bjelkevik (2005). Here foundation (FN) is included in structural (ST). Overtopping (OT) has been replaced by water (W), which include to high water levels and overtopping. Seepage (SE) has been replaced by leakage (L), as all dams are exposed to natural seepage. Two new categories have been introduced to better fit the Swedish data. Operational (OP) has been introduced to cover human faults/mistakes and external defects (ED) to group causes like external erosion, cracks and settlements into one category. By introducing initiating cause the Swedish reporting system have the potential of reporting sequential events as well. This results in events like piping and sinkholes not being included, as those kinds of events never are the initiating cause, but more the result of internal erosion for example. In Figure 4 the number of different dams reported in each category is given as percentage of the total number of dams reported (33). This has been introduced to show weather the events take place at the same dam all the time or if it happens to different dams.

Figure 4 shows that structural (ST) stands for most events, followed by internal erosion (IER) with the same number of incidents. Comparing the number of dams shows, that structural (ST) stands for about 30% of the total number of dams and internal erosion (IER) for about 20%, which means that for internal erosion (IER) events happens to the same dam more frequently. Water related events (W) are the third most common cause followed by operational (OP), ice and frost (I) and external defects (ED). All three have the same number of events but with a different composition with regard to the seriousness of the event. Here operational (OP) is the only cause initiating a failure.

As for initiating cause the categories for dam type have been slightly changed compared to Bjelkevik (2005) in order to better fit the design of Swedish tailings dams. All categories follows ICOLD (1996) with the exception of the homogeneous rock fill dam (D), which in ICOLD (1996) is a dam of tailings material, and of the dam type where tailings is placed mechanically according to the upstream construction method (E4). As in Figure 4 the number of dams reported in each category is given as percent of the total number of dams reported.

Figure 5 shows that the majority of Swedish tailings dams, nearly 70%, are staged conventional embankments (B) and, not surprisingly, stands for most of the events (66%), all failures (100%), most incidents (63%) and most event driven maintenance (59%). Tailings dams where the tailings is mechanically places in an upstream design (E4) have the second most incidents (20%), but a very low number of dams in percent of total number of dams. Here, there are only two dams representing all eight events.

Looking at dam fill material in Figure 6 it can be seen that most dams, over 40%, are earth and rock fill dams (E/R), and stands for 55% of the events, which indicates that many earth and rock fill dams are involved in more than one event. The second largest category for dam fill material is earth fill dams (E). Nearly 35% of all reported dams are earth fill dams (E), but they only stand for nearly 30% of the events, which indicates that earth fill dams are not as susceptible as earth and rock fill dams to have repeated events. The statistical data is probably too limited to draw any solid conclusions about the other fill material categories, as they only have one to three events each.

The statistics is normalized against suitable parameters in order to minimize effects like different dam height and production. Other parameters, like dam length, impoundment area or impoundment volume or capacity could have been used as well, but data for this was not available. The normalized data is supposed to give more comparable data even though the international data is not as complete as the Swedish.

Figure 7 and 8 show Swedish and international statistics (ICOLD, 2001) respectively. The figures show type of event normalized against dam height for each year. In the figures different weights are given to different events, i.e failure=3, incidents=2 and event driven maintenance=1. The normalization was then made by dividing the event type by dam height. The international statistics does not have “event driven maintenance”, but have groundwater. What groundwater includes is not explained nor defined and is not included in the Swedish statistics as there are no identified event fitting into the category. In this paper groundwater has got the value of 1. This is the same as event driven maintenance, but when comparing information in the two figures, only failures and incidents should be compared. One event is missing in both figures. In Figure 7 a failure in 1996 is missing because the type of event (3) divided by dam height (2 m) gives 1,5, which is much higher than the rest of the normalized values. For Figure 8 119 of the 221 events included in ICOLD (2001) had the required data to be plotted and one of these 119 events is missing. The event is from 1928 and is therefore not included in the graph. The time period is made the same (1940-2010) in both figures in order to facilitate the comparison of the two figures. It should also be mentioned that none of the Swedish events are included in the international statistics.

In Figure 7 it can be seen that event driven maintenance occur around year 2000. This has been shown before, but it can also be seen that event driven maintenance in general have a lower value (type of event divided by dam height) than incidents and failures. Failures also seem to have the highest general value, even though it is not as obvious as the low values for event driven maintenance. Even in Figure 8 failures seem to have a generally higher value than incidents.

Comparing Figure 7 with Figure 8 show that the majority of reported international events are between 1965 and 1995, whereas the majority of Swedish events are around year 2000. The difference might be due to the fact that the international statistics only comprises events up to the beginning of year 2000, while the Swedish compilation includes events up to year 2004. But it is hypothyzed by the author that the reporting of events in Sweden has improved more than internationally. There are no reasons to believe, that the number of events has increased more in Sweden or that the Swedish tailings dams have become worse in performance. International failure events are more widely spread out, see Figure 8, than the Swedish failure events. These are more or less located around the value of 0,25 m^{-1}. Comparing the value (type of event divided by dam height) it looks about the same in Sweden and internationally.

Swedish events are mainly below 0,2 m^{-1}, and international events are mainly below 0,3 or 0,35 m^{-1}.

Figure 9 to 13 show events normalized with regard to mine production. As ferrous and non ferrous ore (copper, lead, silver, gold and zinc) production numbers differ significantly and with the order of 10^2, they have been analyzed separately. The international statistics (ICOLD, 2001) comprises 82 events out of the 221 within the right time span and with the required data (year and event type). Out of these there are only three events at ferrous mine sites, which is a too low number for an analysis. From the international statistics there are therefore only 79 events at non ferrous mine sites included in this analysis. The normalization has been made by summarizing all event types (failure=3, incident=2 event driven maintenance=1) for each five-year period and then divide the sum by the mean production for the same period. Swedish mine production has been used for Swedish events and world mine production for non-Swedish events.

Figure 9 and 10 has been included to verify that interpolation between the five-year production numbers received from RMD (2005) is justified. The mine production for the European countries is more or less constant, whereas Australia's mine production has increased a lot over the last 15 years. RMD (2005) could not give any information on production for 1980 resulting in this value being interpolated as well as the mean values for each five-year period.

Looking at Figure 11 and 12 it can first be seen that during the time period 1985-1989 no events are documented in Sweden and for ferrous mine sites this is the case for the time period 1990-1994 as well. The reason for this lack of information is believed to be simply lack of administrative awareness and lack of documentation and reporting. Secondly, the normalized number differs with the order of 10^2, which is about the same as the difference in production between the two types of mines. However, the non ferrous mine production is slightly larger than the ferrous mine production even if the order of magnitude is disregarded, but the normalized number shows the opposite, i.e. the normalized number for events at non ferrous mine sites is higher. This indicates that the seriousness of events must be higher at non ferrous mine sites. For the time period 2000-2004 the events represented in Figure 11 (ferrous mines) are two incidents and eight event driven maintenance events, whereas the same numbers in Figure 12 (non ferrous mines) are one failure, nine incidents and one event driven maintenance. This supports the previous statement. The author does not believe, that the difference is due to neither different level of dam safety, awareness nor reporting. A reason for the difference could be that non ferrous mines produce more waste, i.e. tailings, than ferrous mines and therefore have larger tailings dams, which in turn results in more events.

Comparing Figure 12 and 13 show that the normalized number for Sweden is about 20 times higher than for the international statistics. The reason for this is probably due to the more or less correct production statistics and the finite failure statistics, i.e. the lack of reporting internationally. Once again, the author does not believe that the number of events is much higher in Sweden or that the Swedish tailings dams perform worse, but that the international statistics is not complete. It should also be mentioned that the time period 2000-2004 for the international statistics in Figure 13 is not complete. This time period only comprises the first part of 2000 including one event. Therefore this period should not be included in a comparison as the Swedish statistics include reporting for the whole period. If the international statistic was updated it should probably show a higher number for 2000-2004.

The trends for the Swedish and the international statistics differ, see Figure 12 and 13. For Sweden, Figure 12, the trend is increasing during the last 10-year period and seems to come to a constant value around nearly 70 Mt^{-1}. Internationally, Figure 13, the trend is decreasing looking the last 20 years and seems to come to a constant value around nearly 1,0 Mt^{-1}. The international statistics seems to be more complete than the Swedish in a historical perspective (20-30 years back), which is difficult to explain. Looking at the period 1985-1989 Figure 12 and 13 show two opposite pictures. Where the Swedish statistics have no events reported the international statistics have the highest normalized number, almost 3,5 Mt^{-1}. The reason for the lack of data in a historical perspective in Sweden is due to lack of administrative awareness and lack of documentation and reporting. The reason for the international peak at this time period is hard to explain. However, for the more recent time periods (1985-2004) the author does, once again, not believe that the number of events is much higher in Sweden or that the Swedish tailings dams perform worse, but that the international statistics is not complete.

If Sweden is regarded as an average mining country, and used as a base for comparison, the number of events in other countries could be estimated by using data for their production and the production normalized event value, Figure 11 and 12, for Sweden. An attempt to do this for ferrous and non ferrous mines respectively for the time period 2000-2004 has been made. The results are presented in Table 1 and 2 respectively.

The results in Table 1 and 2 show that there are in total about 300 events (failures, incidents and event driven maintenance) happening around the world if Sweden is a used as a base for comparison. There are approximately 200 at non ferrous ore mines and approximately 100 at ferrous. These numbers should be compared with the numbers found in the international statistics, i.e. 1 at non ferrous ore mines and 0 at ferrous for the time period of 2000-2004, but 1-2 events on at annual average (ICOLD, 2001). The author believes that tailings dams in Sweden are neither better nor worse than elsewhere. Therefore the information in Table 1 and 2 should be interesting to compare with actual numbers of events. It may indicate that statistics and systematic compilation of information regarding tailings dam safety could be improved at many places around the world. The author also believes that Sweden, as a relatively small mining company and as a developed country, probably have a higher level of dam safety than the average mining nation, which indicate that the numbers presented in Table 1 and 2 could be even higher. However, this is only estimations, the numbers still indicate that dam safety is and will be of high priority for years come.

Table 1 Estimated number of events per year (failures, incidents and event driven maintenance) occurring at ferrous mine sites in some countries and in the world. Information from Sweden is used as base for comparison.

Estimation du nombre d'événements (ruptures, incident, entretien événementiel) qui se produisent aux mines ferreuses dans quelques pays et dans le monde. Information Suédoise est utilisée comme base de comparaison.

Country	Production [Mt/year]	Sum(event*event type) / production	Total event points/year	Number of events/year
Sweden	4,37	0,549	2,4	2
Spain	0,01	0,549	0,0	0
Rumania	0,03	0,549	0,0,2	0,016
Canada	6,36	0,549	3,5	2,9
Australia	40,55	0,549	22,28	18,5
World	214,5	0,549	117,8	98,2

Table 2 Estimated number of events per year (failures, incidents and event driven maintenance) occurring at non ferrous mine sites (copper, lead, silver, gold and zink) in some countries and in the world. Information from Sweden is used as base for comparison.

Estimation du nombre d'événements (ruptures, incident, entretien événementiel) qui se produisent aux mines non ferreuses (cuivre, plomb, argent, or et zinc) dans quelques pays et dans le monde. Information Suédoise est utilisée comme base de comparaison.

Country	Production [Mt/year]	Sum(event*event type) / production	Total event points/year	Number of events/year
Sweden	0,07	69,0	4,8	2,6
Spain	0,028	69,0	1,9	1,0
Rumania	0,014	69,0	0,94	0,5
Canada	0,32	69,0	22,2	12
Australia	0,57	69,0	39,3	21,3
World	5,24	69,0	361,3	195,7

6. CONCLUSION

It is important to point out that all data used in the present studdy is incomplete, maybe with the exception of production data from RMD (2005). The level of reported data differ, as well as the definition of event types and other terms used.

Dam age at the time of event does not seem to be important as events are evenly spread out. Failures seem to be more present at relatively low dam heights.

Structural (ST), internal erosion (IER) and water related events stands for 60% of the initiating causes for Swedish events.

70% of all reported dams are staged conventional embankments and they represent 66% of the events. The number of events is consequently in the same range as the number of dams. 20% of the dams are embankments where tailings have been mechanically placed in an upstream construction. This dam type represents 14% of the events and is thus under represented.

40% of all reported dams are earth and rock fill dams and they represent 55% of all events, thus indicating that several events happen to the same dam. 35% of the dams are earth fill dams and they represent 30% of all events, which indicates that these dams are normally not subjected to many events.

Normalizing event type against dam height gives about the same picture for Swedish and international tailings dams.

Normalizing against production gives, however, a different picture, more or less the opposite for Swedish and international events and a difference of the magnitude 10^2 between ferrous and non ferrous mine production as well as normalized value. The latter is due to different production, but even taking that into account there is still a difference in the seriousness of event, in favor for non ferrous mines.

Using Sweden as a base for comparison indicates that there are about 300 events per year worldwide, of which about 2 are reported internationally.

7. REFERENCES

Bjelkevik A. (2005). Swedish tailings dams incidents and failures – Lessons learnt. Securing the Future International Conference on Mining and the Environment metals and Energy Recovery. June 27 to July 1, 2005 in Skellefteå, Sweden.

European Commission, European (2004). Reference Document on Best Available Techniques for Management on Tailings and Waste-Rock in Mining Activities (BAT) by European Commission, European IPPC Bureau July 2004. http://www.jrc.es/pub/english.cgi/0/733169 (December 2004)

ICOLD (1996). Bulletin 106: A Guide to Tailings Dams and Impoundments – Design, construction, use and rehabilitation. Published by the International Commission on Large Dams together with UNEP, United Nations Environmental Program, Paris. 239 pps. ISSN 0534-8293, ISBN 92-807-1590-7.

ICOLD (2001). Bulletin 121: Tailings Dams Risk of Dangerous Occurrences – Lessons Learnt from practical experience. Published by the International Commission on Large Dams together with UNEP, United Nations Environmental Program, Paris. 144 pps. ISSN 0534-8293, ISBN 92-807-2053-8. www.icold-cigb.org./ or www.uneptie.org (January 2995)

RMD (2005). Raw materials data, by Raw Materials Group, Stockholm 2005.

Strachan C. (2002). Review of tailings dam incident data. Mining Environmental Mnagement, January 2002. Volume 9, No. 6 (pp 7-9). ISSN 0969-4218. Published bi-monthly by The Mining Journal Limited. Friary Press, London.

8. SUMMARY

Sweden has been a mining nation for more than 1000 years and is one of Europe's major mining countries. Mining wastes, tailings and waste rock, have been produced during the period. The former is the silt and fine sand resulting from the extraction process and normally deposited as a slurry in tailings dams. The tailings dams are sometimes designed as conventional earthfill dams and sometimes constructed of the tailings material itself. In both cases, the dams are often raised in stages or continuously over extended period of times, which is one of the main differences between tailings dams and conventional water retention dams. Another difference is that tailings dams store solids (tailings), water and, in addition, metals and minerals not extracted, as well as remains of the metals or minerals being extracted. Therefore incidents and failures of the embankments might result in unwanted release of substances being hazardous to the environment, especially if spread to rivers and lakes.

From analysis of lessons learnt from reported and analyzed incidents and failures, much can be learnt in order to improve dam safety in the future. This paper presents all the known incidents and failures of Swedish tailings dams and discusses the causes and the consequences. The understanding and analysis of earlier mistakes will help to prevent incidents and/or failures to be repeated. In addition to the analysis of Swedish tailings dams, the paper also presents an international outlook and comparison.

8. RESUMÈ

La Suède avait été un pays minière depuis plus de 1000 ans, et est encore un des plus grands en Europe. Les résidus des opérations minières, les rejets et les débris de roche étaient produits pendant cette période. Les premiers sont les sable fins et limoneux qui résultent de la conduite de l'extraction, et sont normalement déposés comme une pulpe dans une digue à rejets. Les digues à rejets sont parfois conçues comme des réservoirs conventionnels et de temps en temps sont construits des rejets eux-mêmes. Dans les deux cas de l'article présenté, les réservoirs sont souvent érigés en étapes ou sans interruption pendant une période prolongée, qui est une des raison principale des différences entre les digues à rejets et les réservoirs conventionnels pour l'eau. Une autre différence est la rétention des rejets solides et de l'eau des digues à rejets en sus des métaux et minéraux pas extraits et les restes des métaux et minéraux étant extraits. Donc les incidents et les ruptures des barrages des matériaux meubles pourraient résulter en un dégagement des substances non désirées et dangereuses à l'environnement, en particulier si ce dégagement se répand dans des rivières et lacs.

En analysant les leçons des incidents et ruptures ayant rapporté, beaucoup peut être appris afin d'améliorer la sécurité future des barrages. Cet article présente tout ce qui est connu des incidents et ruptures des digues à rejets et discute les causes et conséquences. Une compréhension et analyse des erreurs antérieures aideront à prévenir la répétition des incidents et / ou des ruptures. En plus de l'analyse des digues à rejets suédois, l'article présente également une perspective internationale et comparaison.