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# HIGHWAY BRIDGE DAMAGE AND FAILURE: MECHANISMS AND A COMPARATIVE ANALYSIS OF EXPERIENCE IN KAZAKHSTAN, KYRGYZSTAN AND OTHER COUNTRIES (2006-2026)

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**ABSTRACT**

**Introduction.** Damage to a highway bridge, and still more its collapse, interrupts traffic and freight flows far beyond the crossing itself. The causes named in the literature range from scour and flood action to design and construction errors, corrosion, fatigue cracking, overloading and impact by vehicles or ships. **Materials and Methods.** The review draws on journal papers, official investigation reports and statements of road agencies and emergency services (published by them or by the press) for 2006–2026. Four collapses examined by technical commissions – I-35W, Morandi, Fern Hollow and Francis Scott Key – are set against nine incidents recorded in Kazakhstan and Kyrgyzstan in 2024–2026; for each we noted the mechanism, the contributing factors and how reliably the cause had been established. **Results and Discussion.** Abroad, the cases are mostly about design errors, ageing of the structure and impact. In the regional sample, eight incidents out of nine were triggered by floods, mudflows or oversized machinery, a difference we attribute partly to the bridge stock and partly to what is made public. **Conclusions.** Bridges need risk-based management throughout their service life, in which regular inspection, checks of residual capacity, monitoring of scour and corrosion and control of oversized transport are tied to repairs actually being carried out.

**KEYWORDS**: bridge deterioration; hydraulic actions; foundation erosion; material degradation; fatigue damage; traffic loading; condition assessment.

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# АВТОМОБИЛЬ ЖОЛДАРЫ КӨПІРЛЕРІНІҢ ЗАҚЫМДАНУЫ МЕН ҚИРАУЫ: МЕХАНИЗМДЕРІ ЖӘНЕ ҚАЗАҚСТАН, ҚЫРҒЫЗСТАН МЕН БАСҚА ЕЛДЕРДІҢ ТӘЖІРИБЕСІН САЛЫСТЫРМАЛЫ ТАЛДАУ (2006–2026)

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**АҢДАТПА**
**Кіріспе.** Автомобиль көпірінің зақымдануы, ал құлауы одан да бетер, көлік қозғалысы мен жүк тасымалын өткелдің өзінде ғана емес, бүкіл бағыт бойынша тоқтатады. Ғылыми әдебиетте оның себебі ретінде шайылу мен су тасқыны, жобалау мен құрылыстағы қателер, коррозия, шаршау жарықтары, асқын жүктеме, сондай-ақ көлік немесе кеме соққысы аталады. **Материалдар мен әдістер.** Шолуда 2006–2026 жылдарды қамтитын журнал мақалалары, ресми тергеу есептері және жол ведомстволары мен төтенше жағдайлар қызметтерінің хабарламалары (өздері немесе баспасөз жариялаған) пайдаланылды. Техникалық комиссиялар зерттеген төрт апат – I-35W, Моранди, Fern Hollow және Francis Scott Key – 2024–2026 жылдары Қазақстан мен Қырғызстанда тіркелген тоғыз оқиғамен қатар қойылды; әрқайсысы үшін механизм, қосалқы факторлар және себептің қаншалықты сенімді анықталғаны белгіленді. **Нәтижелер және талқылау.** Шетелде көбіне жобалау қателері, конструкцияның ескіруі және соққы кездеседі. Аймақтық іріктемеде тоғыз оқиғаның сегізі су тасқынынан, селден немесе габариттен тыс техникадан болған; бұл айырмашылықты біз ішінара көпірлер қорымен, ішінара жария етілетін ақпаратпен түсіндіреміз. **Қорытынды.** Көпірлерді бүкіл қызмет мерзімі бойы тәуекелге сүйеніп басқару қажет: тұрақты тексеру, қалдық жүк көтергіштікті тексеру, шайылу мен коррозияны бақылау және габариттен тыс тасымалды қадағалау жөндеу жұмыстарының нақты орындалуымен байланыстырылуы тиіс.

**ТҮЙІН СӨЗДЕР:** көпірлердің тозуы; гидравликалық әсерлер; іргетастың шайылуы; материалдың деградациясы; шаршау зақымдары; көлік жүктемесі; техникалық жай-күйді бағалау.
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# ПОВРЕЖДЕНИЯ И ОБРУШЕНИЯ АВТОМОБИЛЬНЫХ МОСТОВ: МЕХАНИЗМЫ И СРАВНИТЕЛЬНЫЙ АНАЛИЗ ОПЫТА КАЗАХСТАНА, КЫРГЫЗСТАНА И ДРУГИХ СТРАН (2006–2026)

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**АННОТАЦИЯ**

**Введение.** Автомобильные мосты обеспечивают движение, связность территорий и работу логистических цепочек, поэтому их повреждение или обрушение отражается далеко за пределами самого сооружения. Причинами отказов становятся гидравлические воздействия и размыв, дефекты проектирования и строительства, коррозия, усталость, перегрузка, удары транспортных средств и судов. **Материалы и методы.** Проанализированы научные публикации, отчеты официальных расследований, сообщения ведомств и СМИ об инцидентах на мостах за 2006–2026 гг. Четыре зарубежные аварии, изученные в ходе технических расследований (I-35W, Морандиевский виадук, Fern Hollow, Francis Scott Key), сопоставлены с девятью случаями в Казахстане и Кыргызстане за 2024–2026 гг. Каждый случай классифицирован по механизму, сопутствующим факторам и уровню достоверности установленной причины. **Результаты и обсуждение.** Среди зарубежных аварий преобладают ошибки проектирования, деградация конструкций и внешние удары, тогда как восемь из девяти региональных случаев связаны с паводками, селями или негабаритной техникой. Это различие отражает и особенности парка сооружений, и состав публично доступной информации. **Выводы.** Безопасность мостов требует риск-ориентированного управления на протяжении всего срока службы: регулярных обследований, оценки остаточной грузоподъемности, контроля размыва, коррозии и негабаритных перевозок, а также обязательного доведения результатов обследований до ремонта.

**КЛЮЧЕВЫЕ СЛОВА:** деградация мостов; гидравлические воздействия; размыв оснований; деградация материалов; усталостные повреждения; транспортная нагрузка; оценка технического состояния.

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## 1 INTRODUCTION

Traffic, weather, vibration and daily and seasonal temperature changes act on a road bridge for decades, while its materials slowly age. Because the members work together as a spatial system, damage to one critical component throws load onto its neighbours, and in a structure with little redundancy this can end in progressive collapse [3, 11, 13, 14].

Freight volumes and axle loads keep growing, much of the existing stock is old, and dangerous natural events seem to occur more often than before [1, 3, 11, 12]; keeping bridges safe under these conditions is what makes the topic relevant. Of particular concern are scour around pier foundations, hidden corrosion of steel connections, fatigue cracking, deterioration of concrete and reinforcement, and local defects that a routine visual inspection may miss [4, 5, 7, 21, 24].

Zhang et al. [1], summarizing ten earlier studies, grouped the causes of bridge failure into design errors, construction faults, hydrological action, collisions and overloading. They argue for a common classification of failures and for closer attention to stability, fatigue strength and maintenance [1, 3]. National surveys point the same way: an analysis of four decades of bridge failures in India also found natural hazards and material deterioration among the recurring causes [23].

Three terms need to be kept apart if case data are to be compared consistently. *Damage* is deterioration of a structure or a component; *failure* is the inability of a component or system to perform its required function; *collapse* is partial or total structural failure with loss of load-bearing capacity [1, 3]. Without this distinction, statistics from different sources cannot be compared, and preventive measures risk being aimed at the wrong problem [1, 6, 8].

Individual failure mechanisms are well studied. The practical difficulty lies in judging how design defects, natural hazards, traffic loads and shortcomings in operation act together [1–3, 6, 7]. For this reason the bridge failures of 2006–2026 are treated here not as a list of incidents but as material for identifying recurring mechanisms and preventive engineering measures [1, 2, 5, 8].

The aim of the study is to analyse damage to and collapses of road bridges in 2006–2026 in international practice and in Kazakhstan and Kyrgyzstan, to identify their main causes and to propose technical measures that improve the reliability of structures over their life cycle.

To achieve this aim, the study addresses the following tasks:

1. To systematize the main types of damage to road bridges and the mechanisms by which they develop.
2. To analyse typical failure cases in different countries, distinguishing confirmed causes from preliminary versions.
3. To identify the links between design flaws, external actions and the quality of operation.
4. To identify promising methods of bridge inspection, monitoring and failure prevention.
5. To formulate recommendations for applying international experience to bridge operation in Kazakhstan.

## 2 METHODS AND MATERIALS

### *2.1. Sources of information and approach to analysis*

The study is an analytical review of published evidence on damage to and failure of highway bridges between 1 January 2006 and 12 October 2026. The evidence base comprises peer-reviewed publications on failure mechanisms, studies of hydraulic bridge failures, reports of official investigations by the US National Transportation Safety Board (NTSB) and the Italian Ministry of Infrastructure and Transport and, for the regional cases, official statements of road agencies, emergency services and local authorities as published by these bodies or by news media [1–7, 10, 16–20, 26–38].

The review by Zhang et al. [1] and the study of

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hydraulic bridge failures by Xiong et al. [2] served as the main background sources. Xiong et al. analysed a database of about 1,700 cases spanning two centuries and identified scour, flooding and ice action as the main hydraulic failure mechanisms [2].

Cases were selected according to the following criteria:

• public evidence of damage to or collapse of a highway bridge;

• technical information on the established or suspected cause;

• enough detail to identify the immediate damage mechanism and the contributing factors;

• relevance to bridge design, inspection, maintenance or operation.

The sample is purposive rather than exhaustive and is not used to estimate failure rates. To make the strength of the evidence explicit, each case was assigned one of three levels: confirmed by a technical investigation; official statement of the responsible agency; or preliminary version (for example, an initial statement by law enforcement). Cases known only from a single unofficial report and not confirmed by a primary source were excluded [1, 2, 6–8].

### *2.2. Classification of damage causes*

For comparison, the causes are grouped into five categories (Fig. 1).

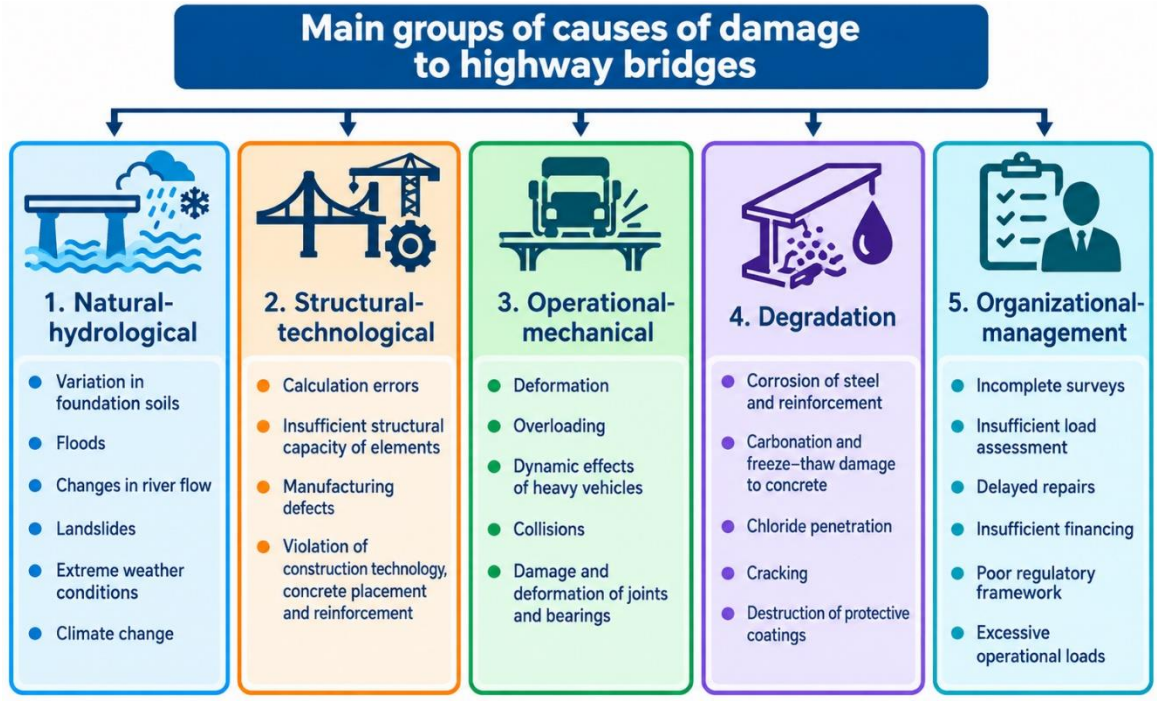



**Fig. 1.** The main causes of damage to road bridges

The categories overlap. Scour, for example, may directly cause a pier to lose stability, while the absence of water-level monitoring and a late closure of the bridge are organizational factors in the same event.

### *2.3. The methodology of determining the causes*

Each incident was analysed with a cause-and-effect scheme (Fig. 2).

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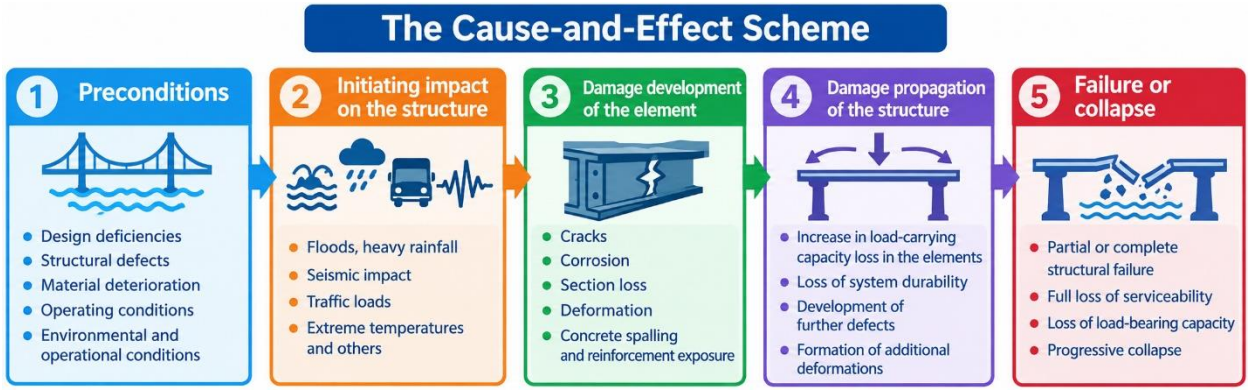



**Fig. 2.** Causal scheme of damage and destruction of a highway bridge

The scheme separates the initial defect, the factor that directly triggered the failure and the circumstances that made the consequences worse.

Three further characteristics were examined: the condition of the load-bearing elements before the incident, whether there were warning signs, and whether inspection, repair or traffic restrictions could have prevented the failure.

## 3 RESULTS AND DISCUSSION

### *3.1. The main patterns of damage to road bridges*

Published reviews agree that bridge damage stems both from internal factors – design errors, insufficient strength, manufacturing defects and accumulated deterioration – and from external actions such as floods, collisions and increased loads. In the review by Zhang et al. [1], five categories (design errors, construction faults, hydraulic action, collisions and overloading) together accounted for more than 70% of the cases compiled from earlier studies. That figure describes their compiled sample and should not be transferred automatically to other countries or to 2006–2026. Hydraulic action deserves particular attention: in the database of Xiong et al. [2] it caused about half of all failures, mainly through scour of foundations, flooding and ice. Again, the share characterizes that database rather than a worldwide failure rate. Table 1 summarizes the main mechanisms and how they show up in practice.

**Table 1.** The main causes of damage to road bridges and the mechanisms of their development

| Cause group | Damage mechanism | Typical indicators | Possible consequences |
|---|---|---|---|
| Hydraulic | Scour around the foundation | Bed-level lowering, exposed piles, support settlement | Loss of support stability; span collapse |
| Structural | Insufficient capacity of joints or members | Deformation, cracking, local instability | Local or progressive failure |
| Fatigue | Crack growth under cyclic loading | Cracks near welds, holes, and connections | Sudden fracture of a member |
| Corrosion | Loss of effective metal or reinforcement section | Rust, coating delamination, section loss | Reduced strength and durability |
| Dynamic impact | Impact, collision, or increased dynamic response | Damage to supports, girders, or barriers | Local damage or loss of stability |

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| | | | |
|---|---|---|---|
| Construction-related | Defects in concreting, erection, or prestressing | Voids, cracks, geometric deviations | Insufficient strength and excessive deformation |
| Operational | Overloading or changes in operating conditions | Increased deflection, vibration, crack width | Accelerated accumulation of damage |
| Organizational | Unresolved defects or incorrect condition assessment | Repeated findings in inspection reports | Progression from local defects to an unsafe condition |
| *Note. The table represents an engineering classification of damage mechanisms, rather than a statistical distribution of accidents by cause.* | | | |

Severe incidents rarely have a single cause. More often a reduced load-carrying capacity, an adverse event and inadequate inspection or risk control coincide. Safety assessment should therefore consider the actual condition of the structure, its operating conditions and the consequences of failure, not only its design strength.

### *3.2. Analysis of typical bridge accidents in the USA and Italy*

Four well-documented collapses in the United States and Italy were examined to compare different failure scenarios: the I-35W, Morandi, Fern Hollow and Francis Scott Key bridges. Between them they cover a design deficiency, long-term deterioration with maintenance failures, and an external vessel impact.

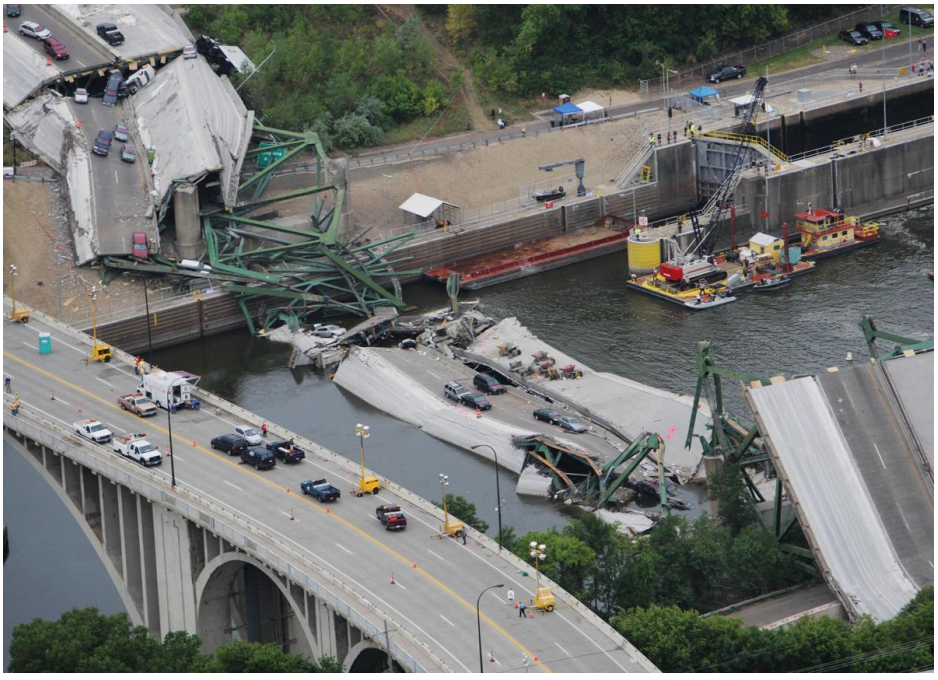


**Fig. 3.** Failure of the gusset plates: I-35W bridge, Minneapolis, USA, 2007 [Authors material]

On 1 August 2007 the central section of the steel truss bridge over the Mississippi River collapsed. The NTSB concluded that the probable cause was the inadequate load capacity of the gusset plates at the U10 nodes, which resulted from a design error. Contributing factors were the increase in dead load after earlier modifications and the heavy concentration of construction materials and equipment on the deck at the time of the

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collapse, together with traffic loads. Weaknesses in the design review process meant that the critical vulnerability was not identified in time [16].



**Fig. 4.** Collapse of the cable-stayed Morandi viaduct, Genoa, Italy, 2018 [Authors material]

On 14 August 2018 part of the Polcevera viaduct in Genoa, known as the Morandi Bridge, collapsed. The case shows how vulnerable a large structure becomes when the condition of its stays, reinforced concrete members and load-transfer joints, and its overall deterioration, are not assessed as a whole. For engineering analysis it underlines the need to consider together the condition of the load-bearing elements, long-term effects, repair history and design features. Conclusions about the specific mechanism and about responsibility should rest on the technical investigation, such as the report of the inspection commission of the Italian Ministry of Infrastructure and Transport [20], rather than on the appearance of the wreckage.



**Fig. 5.** Corrosion and unrepaired defects: Fern Hollow Bridge, Pittsburgh, USA, 2022 [Authors material]

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On 28 January 2022 the Fern Hollow Bridge collapsed after a critical steel member failed at its south-west support. According to the NTSB, the cause was extensive corrosion and section loss associated with accumulated water and debris. Earlier inspection reports had repeatedly called for maintenance and repair, but the recommendations were not acted on in time. Shortcomings in the inspections, incomplete identification of fracture-critical elements and errors in load rating also contributed [17, 18].

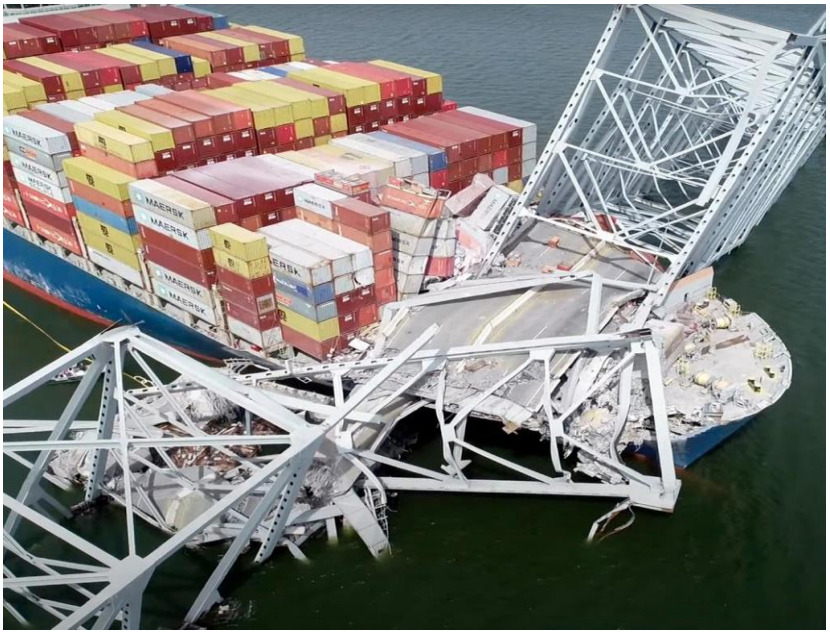


**Fig. 6.** Vessel collision with a pier: Francis Scott Key Bridge, Baltimore, USA, 2024 [Authors material]

On 26 March 2024 the container ship Dali struck a pier of the Francis Scott Key Bridge, and a large part of the structure collapsed. According to the NTSB, the ship lost propulsion and steering after an electrical power failure. The vulnerability of the bridge to impact by a large vessel and the absence of adequate pier protection made the consequences far worse [19]. The case shows that the safety of a road bridge depends not only on its strength but also on pier protection, on the assessment of external threats and on emergency response.

The four cases begin differently: a design deficiency combined with construction and traffic loads at I-35W; long-term deterioration with disputed causal contributions at Morandi; corrosion compounded by inadequate maintenance at Fern Hollow; and a vessel impact at Francis Scott Key. In each, the severity of the outcome depended on how vulnerable the structure was, on the initiating event and on how well inspection, maintenance and risk control worked.

### *3.3. Experience of Kazakhstan and Kyrgyzstan: analysis of typical cases of damage and destruction of bridges*

To identify typical causes of damage to bridges in Kazakhstan and Kyrgyzstan, we examined cases from 2024–2026. They include impacts of oversized equipment on load-bearing members, washout of carriageways and approaches by floodwater, destruction of piers by mudflows and a partial collapse attributed to heavy traffic. The cases differ in mechanism and in how well they are documented. Each description below rests on a primary source – an official statement of a road agency, emergency service or local authority, published by that body or by news media – and

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the level of evidence for each case is given in Table 2.




**Fig. 7.** Damaged reinforced concrete girders of the Kalkaman overpass, Pavlodar region, Kazakhstan, 2025 event: [31]

On 21 November 2025 construction equipment struck the overpass of the Kalkaman interchange on the Astana – Pavlodar highway. A Shacman truck was towing a HITACHI excavator on a rigid coupling, and the raised bucket hit the girders; the posted clearance was 5.5 m. Two reinforced concrete beams were damaged: the concrete cover and core concrete were destroyed, and cracks and ruptured and bent reinforcement were recorded. KazAvtoZhol closed the interchange section from midnight on 22 November because the edge beams of the superstructure had been damaged in a traffic accident [31].

From an engineering standpoint, the direct cause was that the transported equipment exceeded the permissible height. Ruptured reinforcement and destroyed concrete suggest a possible loss of flexural and shear capacity, all the more so because the crack resistance of concrete governs the behaviour of such members [15]. The extent of the loss cannot, however, be judged from photographs: it requires an inspection, measurement of the actual damage and calculation of the residual capacity. Published accounts differ as to which beam was damaged most, so its position is not given here without a technical report. The preliminary cost of two new beams was put at no less than 100 million tenge; this should not be read as the final cost of restoring the structure.



**Fig. 8.** Mechanical damage to the Aktau overpass, Astana – Karaganda – Almaty highway, Kazakhstan, 2026 [Authors material]

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On 7 September 2026, at about 14:20, a Volvo truck with a low-loader carrying an excavator struck the Aktau overpass at km 165 of the Astana – Karaganda – Almaty highway. JSC NC KazAvtoZhol confirmed mechanical damage and an inspection of the structure.

This case also belongs to damage linked to heavy equipment and to clearances at structures. The published reports, however, say nothing about which elements were damaged, the condition rating of the overpass, the results of the structural assessment or the outcome of repairs. Without inspection results it is too early to judge how much capacity was lost or whether any members need replacing.



**Fig. 9.** Washout of the bridge deck near Bozai, Abai region, Kazakhstan, 2024 event: [28]

At the end of March 2024 rising water in the Ayagoz River washed out the bridge deck at km 20 of the Ayagoz – Bozai local road; the bridge was closed to traffic and the district akimat declared a local emergency [28]. The damage was primarily hydrological: higher discharge and flow intensity created conditions for erosion of the embankment and of the crossing. Washout of approaches by spring floodwater is a known problem for bridges in Kazakhstan [9]. In assessing such events one has to distinguish between damage to the deck and approaches, damage to piers and collapse of the superstructure. The official report confirmed washout of the deck but did not establish that the supporting structures had failed. Identifying the mechanism would require data on the water level, flow velocity, foundation condition, slope protection and the discharge capacity of the crossing.



**Fig. 10.** Flood damage to the bridge near Tassai, Abai region, Kazakhstan, 2024 event: [29]

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In spring 2024 a flood destroyed the only bridge linking the village of Tassai with the district centre of Kokpekty in the Abai region; traffic used a temporary crossing until a new bridge was opened in June 2026 [29, 30].

The case shows why the flood resistance of bridge crossings has to be assessed: channel capacity, stability of abutments and embankments, protection of foundations against scour and the possibility of local zones of high flow velocity [9]. The available information does not, however, allow the scour depth, the condition of the foundations or the contribution of individual factors to be quantified. The 2026 report on the new bridge concerns the consequences of the same event and is not treated as a separate incident.



**Fig. 11.** Subsidence and partial collapse of the bridge over the Badam River, Shymkent, Kazakhstan, 2024 (event: [26])

During the night of 7 June 2024 the bridge over the Badam River on the Zhanatalap – Sirgeli section in Shymkent subsided and partly collapsed. According to the local authorities, heavy rain raised the water level and the flow washed out the bridge supports. The bridge was closed, and a temporary crossing was later built to restore access [26, 27].



**Fig. 12.** Another view of the partially collapsed Badam River bridge, Shymkent, Kazakhstan, 2024 [Authors material]

The mechanism reported here is hydraulic scour of the pier foundations. Scour removes soil around the foundations, increases the unsupported length of the substructure and redistributes forces in the load-bearing system. Establishing the actual mechanism and the extent of damage would still require an inspection of the foundations, piers and superstructure. The available reports confirm a partial collapse but give no basis for

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quantifying the remaining capacity of the bridge.



**Fig. 13.** Partial collapse of the bridge over the Big Chüy Canal, Novopokrovka – Sary-Zhon road, Kyrgyzstan, 2025 (event: [32])

On 3 May 2025, at about 17:00, part of the bridge over the Big Chüy Canal on the Novopokrovka – Sary-Zhon road in the Chüy region collapsed, and one traffic lane became unusable. Preliminary information from law enforcement pointed to heavy trucks as a possible cause. According to the road enterprise Kyrgyzavtozhol-Sever, the bridge was built in 1966 and is about 40 m long and 7 m wide; it had been inspected on 19 April, and after the incident the Kyrgyzdortransproekt institute carried out a technical examination. Nobody was injured. The bridge was repaired, strengthened and reopened to cars only, with trucks to be admitted after a new bridge is built [32, 33].

For judging the actual capacity of bridges in service, the case is instructive. Age by itself says little: a bridge built in 1966 may still be in fair condition. What matters is the state of the load-bearing members, how far real loads exceed the design ones, what was repaired and when, and whether the materials have changed. No final technical conclusion has been published, so we keep heavy traffic as a preliminary version and do not treat it as an established cause.

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**Fig. 14.** Erosion of the bridge approaches in Ak-Tam, Jalal-Abad region, Kyrgyzstan, 2026 (event: [34])

On 11 May 2026 a mudflow caused by heavy rain washed out the bank protection and approaches on both sides of the concrete bridge at km 23.8 of the Kerben – Ala-Buka – Chatkal road in the village of Ak-Tam (Ala-Buka district, Jalal-Abad region). The damaged sections were concreted and the bridge opened again on 12 May, but water damaged the approaches once more, and on 20 May the Ministry of Transport allowed only passenger cars to cross [34, 35].

We count all these reports as one incident at one structure; the second notice of restrictions continues the story and is not a new event. What failed here were the approaches – nobody reported damage to the superstructure itself. For crossings of this kind the practical tasks are fairly obvious: check whether the embankment cones are stable, reinforce the banks, lead surface water away and protect the approaches from mudflows. Detailed damage parameters and inspection results are not available.



**Fig. 15.** Pier washed out by a mudflow, Ak-Zhol – Zholborstu road, Jalal-Abad region, Kyrgyzstan, 2026 (event: [36])

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On 20 May 2026, at about 02:30, a mudflow caused by heavy rain undermined and carried away one of the piers of the bridge at km 1.3 of the Ak-Zhol – Zholborstu road in the Aksy district of the Jalal-Abad region. The Ministry of Transport of the Kyrgyz Republic reported no casualties; traffic on the section was stopped and the road maintenance enterprise started repairs [36].

Losing a pier is a different matter from losing a deck or an approach, because the load path itself is broken: the superstructure has to redistribute its forces, and further collapse becomes possible. Before such a bridge can be restored, engineers have to find out in what state the remaining piers, the foundations, the superstructure and the channel protection are. As long as no technical report exists, nothing definite can be said about the damage to the other elements or about residual capacity.



**Fig. 16.** Damaged bridge over the Chon-Ak-Suu River, Grigoriev Gorge, Issyk-Kul region, Kyrgyzstan, 2026 (event: [37])

Heavy rain on the night of 2 July 2026 made the Chon-Ak-Suu River in the Grigoriev Gorge (Issyk-Kul region) rise sharply; the water damaged one of the bridges, which then had to be closed. A week later, on 9 July, the bridge was reported repaired and open again [37, 38]. Local reports call it the “fifth bridge”; this is simply its name on the route and does not mean that five bridges were damaged.

The damage was caused by the flood. For bridges in similar settings, an assessment would look at how much water the channel can pass, how likely and how fast the river rises, what the flow does to piers and banks, and how well the foundations resist scour. The published information neither lists the defects nor says which elements suffered. We regard the repair as part of the response to this same event rather than as a separate incident.

Looking back at the nine regional cases, they fall into a small number of scenarios. Twice, transported machinery struck an overpass; several times floods washed out decks or approaches; once a mudflow took away a pier; and in one case a partial collapse was linked to overloading, though only in a preliminary version. Not all of these are equally well documented, and the washout of an approach or a deck should not be presented as a span collapse unless documents confirm it. Two lines of prevention follow. One concerns clearances and the transport of equipment: the real height of the load has to be measured, the bucket and other working parts locked in transport position, the clearances along the whole route known in advance and restrictions actually enforced. The other is hydrological – where floods and mudflows are frequent, the capacity of the channel, the stability of foundations and approaches, drainage and the

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protective works need regular assessment. As soon as cracks, deformation, damaged concrete or reinforcement, or scour at piers are noticed, the bridge should be inspected, and the choice between keeping traffic, restricting it or closing the bridge ought to follow from an engineering inspection and a residual-capacity calculation; a quick look from the roadside is not enough.

### *3.4. Hydraulic impacts and erosion of support bases*

Among the threats to bridges, hydraulic action is one of the most serious. A flood raises the discharge and the water level, reshapes the channel, moves more sediment and digs local scour holes around piers. As soil is gradually taken from under a foundation, or piles become exposed, the foundation loses stiffness, the pier starts to move more, and forces in the superstructure shift. Climate change is expected to make such short-term hazards more frequent and to combine them with long-term stressors such as corrosion [22].

Xiong et al. [2] found that hydraulic causes account for roughly half of the failures in their database and noted that scour, floods and ice can bring a bridge down with little warning. What makes scour so treacherous is that there may be nothing to see from the outside until the scour depth becomes critical [4]. A bridge whose superstructure looks fine can therefore lose much of its stability because of what happens to its foundations.

For Kazakhstan this applies first of all to bridges on rivers with strongly seasonal runoff, large swings in flood level and a heavy sediment load. Still, the risk at a particular site should be judged from local hydrological records, the geometry of the channel, the type of foundation and geotechnical data, and not simply from the region where the bridge stands.

We consider the following measures advisable against hydraulic damage:

- channel surveys with measurement of scour depth before and after each flood season;
- water-level gauges and, on the most critical bridges, scour monitoring;
- recalculation of foundation capacity whenever the bed level changes;
- inspection of slope protection, embankment cones and banks;
- threshold water levels at which traffic is restricted or the bridge is closed temporarily.

### *3.5. Corrosion, fatigue and degradation of load-bearing elements*

Corrosion and fatigue are most dangerous where a bridge has steel trusses, welded joints, steel piers, stay cables or prestressed members. They are driven by long service under load, moisture and aggressive substances, failing protective coatings and poorly detailed joints. As corrosion eats into a cross-section it also creates local stress concentrations, and these are exactly the places where fatigue cracks start and then grow with every heavy vehicle that passes. A crack that reaches critical size can lead to sudden fracture, even when the structure showed little overall deformation beforehand. The Morandi viaduct, which collapsed in 2018, is often discussed in this context. Researchers have proposed a combination of corrosion, fatigue of the stays and insufficient redundancy as a possible mechanism [21]; such research scenarios are not the same as a final finding on all causes, and the Italian Ministry of Infrastructure and Transport has published the conclusions of its own inspection commission [20]. Fern Hollow gives a second example. There, corrosion developed unevenly in places where water and debris collected, and the defects were recorded again and again without the repairs that inspectors had asked for [17]. Visual inspection combined with instrumental methods (Fig. 17) is the most reliable way to assess this kind of damage.

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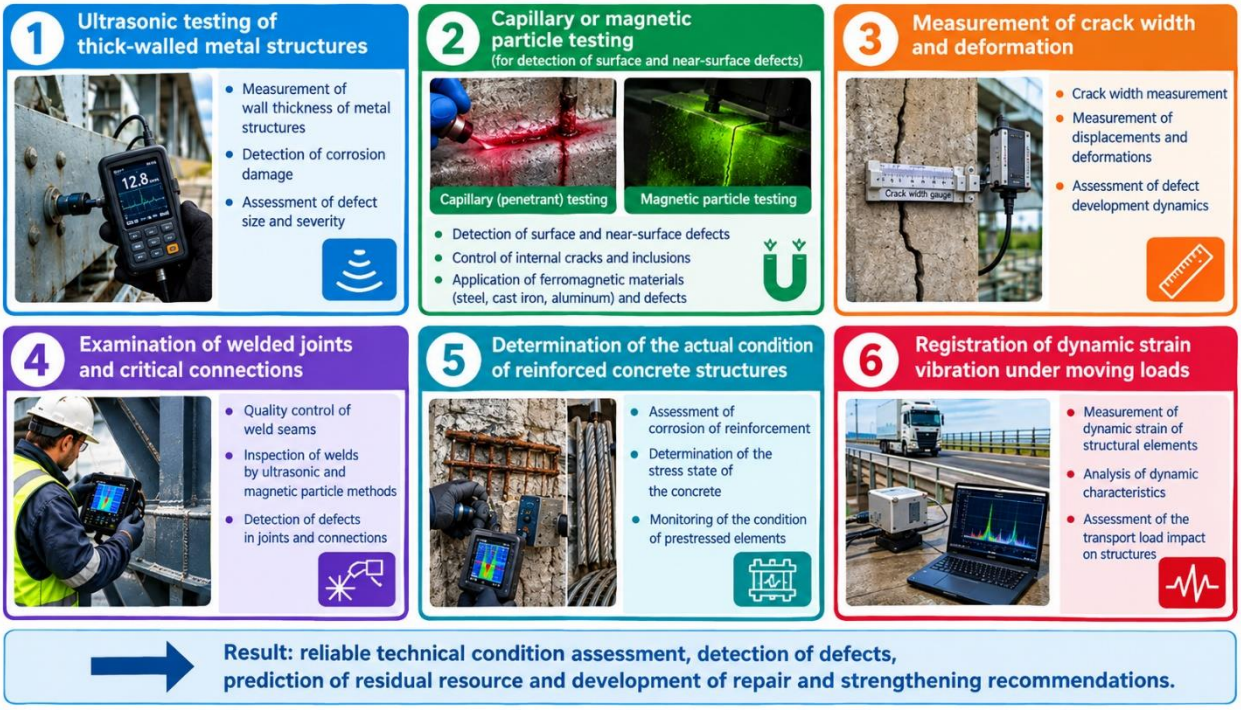



**Fig. 17.** Integrated approach to assessing the technical condition of road bridges

Several complementary methods reveal defects that are hard to find visually and show not only whether damage is present but how it affects the residual capacity.

### *3.6. Design errors, load changes and collisions*

Structural causes of damage include errors in design models, insufficient strength of joints, load combinations that were not considered, local instability and lack of redundancy. Even a correctly designed bridge may cease to match its actual service conditions once the dead load changes, traffic grows or the structure is rebuilt.

The I-35W collapse showed how important it is to check gusset plates and other connections correctly, to verify the actual capacity and to account for additional loads. The NTSB found that the design error in the gusset plates combined with increased dead load and concentrated construction loads [16].

The Baltimore collapse illustrates another mechanism – an external collision with a pier. Here safety depends not only on the strength of the pier but on protective structures, on the capacity to absorb an accidental impact and on the ability of the structure to limit the spread of failure. The NTSB pointed to the lack of measures to reduce the vulnerability of the Francis Scott Key Bridge to collisions with large ships [19].

Where heavy freight traffic uses a bridge, actual loads must be assessed: axle loads, vehicle configuration, traffic volume, dynamic factors, the possibility of several heavy vehicles on one span at the same time and the condition of the road surface [13].

A condition assessment must not be replaced by a formal check against the original design. Operational safety depends on the actual cross-sections, the condition of joints, existing defects, the history of reconstruction and the actual loading.

### *3.7. Comparative assessment of world experience*

Table 2 brings the cases together and states, for each of them, how firmly the cause has been established and which source this rests on.

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**Table 2.** Typical road bridge failures in 2006–2026: mechanisms, lessons and level of evidence

| Bridge and country | Year | Primary mechanism | Important contributing factor | Key engineering lesson | **Level of evidence; source** |
|---|---|---|---|---|---|
| I-35W, United States | 2007 | Failure of gusset plates | Design errors and increased loads | Check critical connections and current load-carrying capacity | Confirmed by technical investigation (NTSB) [16] |
| Morandi, Italy | 2018 | Partial collapse of the cable-stayed viaduct | Element deterioration and long-term inspection issues | Assess the entire load-bearing system | Official inspection commission report [20]; research hypotheses [21] |
| Fern Hollow, United States | 2022 | Failure of a corroded member | Unrepaired defects and inspection deficiencies | Ensure that repair recommendations are implemented | Confirmed by technical investigation (NTSB) [17, 18] |
| Francis Scott Key, United States | 2024 | Collapse after a vessel struck a pier | Vulnerability to external impact | Assess collision risk and protect piers | Technical investigation (NTSB) [19] |
| Badam River bridge, Shymkent, Kazakhstan | 2024 | Partial collapse following scour | Heavy rain and rising water levels | Inspect foundations and assess scour risk | Official statement (local authorities) [26, 27] |
| Bridge near Bozai, Abai Region, Kazakhstan | 2024 | Washout of the bridge roadway | Floodwater and flow action | Check hydraulic capacity and protect approaches | Official statement (district akimat) [28] |
| Bridge near Tassai, Abai Region, Kazakhstan | 2024 | Flood-related damage/destruction | Insufficient flood resilience; individual contributions unverified | Assess the flood resistance of supports, embankments, and foundations | Official statement (regional akimat) [29, 30] |
| Kalkaman overpass, Kazakhstan | 2025 | Damage to two reinforced-concrete girders by an excavator bucket | Exceedance of the available clearance | Verify transported-equipment height and route clearances | Official statement (KazAvtoZhol) [31] |
| Bridge over the Big Chüy Canal, Kyrgyzstan | 2025 | Partial bridge collapse | Possible heavy-truck overloading; cause preliminary | Check actual capacity, member condition, and permitted loads | Preliminary version (law enforcement); road agency statement [32, 33] |
| Bridge near Ak-Tam, Kyrgyzstan | 2026 | Erosion of bridge approaches | Mudflow following heavy rain | Stabilize embankment cones and provide drainage and erosion protection | Official statement (Ministry of Transport, KR) [34, 35] |
| Bridge on the Ak-Zhol–Zholborstu | 2026 | Washout of one bridge support | Mudflow and water action on the foundation | Assess foundation and pier stability | Official statement (Ministry of |

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| | | | | | |
|---|---|---|---|---|---|
| road, Kyrgyzstan | | | | and inspect after mudflows | Transport, KR) [36] |
| Bridge over the Chon-Ak-Suu River, Kyrgyzstan | 2026 | Damage after heavy rain and rising water | Affected members not identified in available reports | Assess hydraulic capacity and support stability | Official statement (emergency services, KR) [37, 38] |
| Aktau overpass, Kazakhstan | 2026 | Mechanical impact by a truck transporting an excavator | Possible clearance violation; damage details require confirmation | Control oversized loads and inspect after impact | Official statement (KazAvtoZhol) |

Three general lessons follow from the cases. First, a local defect becomes critical when the element has little reserve capacity or redundancy, or when its failure causes a large redistribution of forces. Second, an inspection system improves safety only if its findings lead to risk assessment, prioritised funding, timely repair and verification of the result. Third, prevention has to cover both frequent deterioration mechanisms and rare, high-consequence events such as extreme floods and ship collisions.

The two groups of cases also differ in their risk profile. Eight of the nine regional cases were caused by hydrological action (floods, mudflows, scour) or by impact of oversized equipment, and only one, the Big Chüy Canal bridge, is attributed – preliminarily – to overloading of an old structure. None was linked to corrosion or fatigue. Among the international cases the picture is reversed: three of the four collapses involved a design error, long-term deterioration or corrosion, and only one an external impact. Three explanations are possible, and they are not mutually exclusive. The first is the bridge stock: the regional network consists largely of small and medium reinforced concrete bridges over rivers and canals, with few of the steel trusses and cable-stayed structures in which corrosion and fatigue govern. The second is the completeness of public information: a washed-out bridge or a damaged girder is visible and quickly reported, whereas gradual deterioration surfaces only in inspection reports, which are rarely published. The third is case selection: the international examples were chosen because they had been thoroughly investigated, which favours slowly developing, technically complex failures.

The national data point in the same direction. In November 2026 the press, citing the Ministry of Transport, gave the following figures: of 3,623 road bridges in Kazakhstan, 1,488 are on national and 2,135 on local roads; 142 bridges, all but one of them on local roads, are in emergency condition; another 420 local bridges are unsatisfactory; and the share rated good is 50.5% on the national network but only 31.5% on local roads [39]. On local roads, then, about every fifth bridge is unsatisfactory and roughly every fifteenth is in emergency condition – and yet deterioration is almost absent from the incidents that reach the public. We therefore read the lack of corrosion and fatigue cases in our regional sample as a gap in reporting; it does not mean that these mechanisms are unimportant.

### *3.8. Improvement of monitoring and management of technical condition*

Periodic inspections are still needed, but a defect that develops quickly can slip through between two visits. That is why we favour a combined system: regular inspections and non-destructive testing, continuous measurements on critical bridges, and analysis of operating data. On the most critical structures a structural health monitoring (SHM) system can record strain, displacement, vibration, temperature and, if needed, environmental parameters; on

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river bridges, water level, channel condition and scour depth should be measured as well. The data have to be corrected for temperature, season and changing traffic. A shift in natural frequency or vibration amplitude is not necessarily a sign of damage, since temperature or a change of mass or support conditions can produce the same effect, so a diagnosis should be confirmed by several parameters and by inspection on site. The proposed sequence of bridge condition management is shown in Fig. 18.

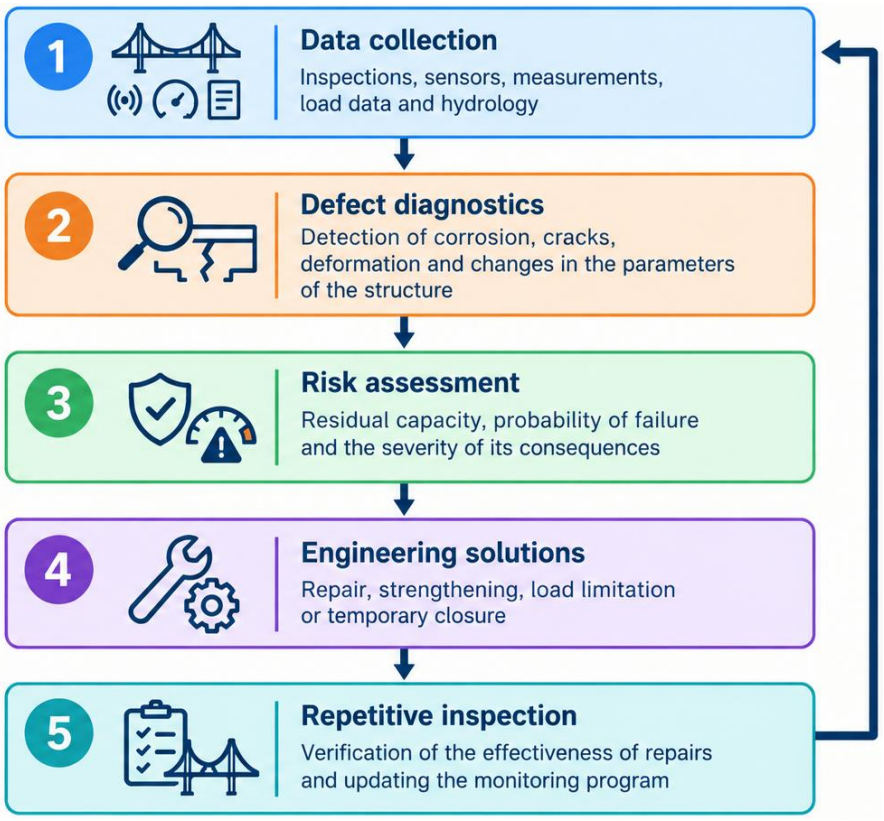



**Fig. 18.** Sequence of bridge condition management

Which bridges get attention first should depend on their condition, the importance of the route, traffic volume, age and exposure to natural hazards. In this way scarce funds go first to the structures where the combination of failure probability and consequences is highest.

### *3.9. Practical significance of the results for Kazakhstan*

Kazakhstan's bridges face wide seasonal temperature ranges, freeze–thaw cycles, moisture, de-icing salts and changing freight traffic; those on rivers also carry flood loads and suffer from channel scour and changing foundation conditions. International experience is therefore directly relevant. Inspection and testing of bridges are governed by SP RK 3.03-113-2014 “Bridges and culverts. Rules for inspections and tests” [40], technical registration (passportization) of bridges is part of the rules for the road database [41], and a bridge management system is being developed into which survey results and digital models of individual bridges are entered [42]. These documents describe how inspections and tests are to be carried out and how structures are registered. As far as we can see, they do not require scour surveys of foundations after floods and mudflows, give no criteria for ranking bridges by risk, and do not say how the implementation of inspection

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recommendations is to be tracked. The measures proposed below are meant to close these gaps; the way the US bridge inspection framework has developed since the 1970s offers a useful point of comparison [25].

In our opinion, operation can be improved most in the following areas:

1. Updating the bridge condition database. Data on design, age, materials, repairs, defects and survey results should be kept for every structure in structured form, inside the road database that already exists [41].

2. Closer control of pier foundations. On flood-prone bridges, channel surveys, scour monitoring and checks of foundation stability should become obligatory, with an extra survey after each significant flood or mudflow.

3. Better diagnostics of steel structures. Joints, welds, members that have lost section and fracture-critical components, whose failure would make the system unstable, need particular care.

4. Assessment of actual capacity. When a bridge has been reconstructed, when traffic composition has changed or when serious defects are found, the structural assessment should be repeated on the basis of the actual condition.

5. Risk-based maintenance. How often a bridge is inspected and when it is repaired should depend on the severity of its defects, how fast they develop and what a failure would cost, and not just on the age of the structure.

6. Digital monitoring. Strategically important bridges would benefit from automatic strain and vibration monitoring connected to the survey database and able to alert the responsible engineers.

An organizational point is just as important: inspection recommendations must actually be carried out. Fern Hollow showed that a defect does not become safer once it is written into a report. If nobody is named as responsible, no deadline is set and nobody checks the result, the control system has a hole in it.

### *3.10 Limitations of the study*

The source data impose several limitations. Not every incident has a technical report, calculations, instrumental survey data or a final conclusion on its cause. For the regional cases we relied on official statements published by agencies and the media; some give only preliminary versions, and later reports sometimes describe the consequences of events already counted. The sample is small and purposive, and the foreign cases were chosen precisely because they had been investigated in depth. What we offer is therefore a qualitative engineering analysis of published incidents – not a complete statistic of bridge failures and not a judgement on the legal responsibility of anyone involved.

## 4 CONCLUSIONS

From the published evidence on damage to and failure of highway bridges in 2006–2026, we draw the following conclusions.

1. Bridges are damaged and collapse for several reasons at once. The main groups are hydraulic action, design and construction errors, corrosion, fatigue, collisions, overloading and shortcomings in operation; how much each matters depends on the database, the region, the type of structure and the classification used.

2. Hydraulic action is one of the main threats. Scour at pier foundations can undermine the stability of a bridge whose superstructure is in good order, which is why hydrological monitoring belongs in bridge management.

3. Corrosion and fatigue can make critical members fail suddenly. Morandi and Fern Hollow show how important it is to find hidden deterioration early, assess residual capacity and repair defects, above all in members whose failure can start a progressive collapse.

4. Design errors and changed loading call for a new safety assessment. I-35W demonstrates that connections and actual loads have to be considered together and that every change in dead load or operating conditions

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should be followed by a capacity check.

5. Protection against external actions is a matter for design and for operation alike. The Francis Scott Key collapse showed the value of assessing ship-collision risk, protecting piers and having a quick emergency response in place.

6. In Kazakhstan and Kyrgyzstan the publicly reported incidents are mostly floods, mudflows and impacts of oversized vehicles, while the deterioration seen in national condition statistics hardly shows up in them. Prevention should move from formal inspection towards risk management, combining instrumental diagnostics, estimates of failure probability and consequences, repair planning and a check that the repairs have worked.

7. For Kazakhstan a combined monitoring system appears the most suitable. It should take account of regional climate and hydrology, the condition of materials, real traffic loads and the role of each bridge in the network; the most critical bridges should be monitored continuously and put first in maintenance programmes.

Making highway bridges safer requires a life-cycle approach in which design, construction, inspection, assessment, repair and operation are linked. The main practical point of this review is simple: once a defect is found, it must lead to timely repair, backed by risk-based monitoring and open records of bridge condition.

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