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ЗАЩИТА ФАСАДОВ ОБЪЕКТОВ КУЛЬТУРНОГО НАСЛЕДИЯ ОТ ВОЗДЕЙСТВИЯ КОСОГО ДОЖДЯ: ОБЗОР ЭКСПЕРИМЕНТАЛЬНЫХ ИССЛЕДОВАНИЙ

Аннотация. Актуальность исследования обусловлена тем, что эрозия поверхности строительных материалов является распространенным явлением, наблюдаемым на фасадах исторических зданий. Климатические изменения могут привести к увеличению частоты и интенсивности экстремальных осадков, что может усилить эрозионные эффекты на фасадах зданий из-за воздействия косого дождя. Целью исследования является сравнение экспериментальных методов оценки степени эрозии поверхности исторических строительных материалов под воздействием косых дождей. Задачами исследования являются обзор современных методов измерения влияния дождя с ветром на поверхностную эрозию и снижение прочности кирпича и известняка; критический анализ наиболее известных методов оценки степени эрозии поверхности строительных материалов; предложение рекомендаций по защите и реставрации поврежденных фасадов объектов культурного наследия из-за воздействия косого дождя.

Значимость полученных результатов для архитекторов и проектировщиков состоит в том, что использование методов оценки степени повреждения фасадов памятников архитектуры из-за косого воздействия дождей позволяют осуществлять мониторинг и выработать меры по защите объектов культурного наследия.

Ключевые слова: косой дождь, эрозия каменной кладки, защита фасадов памятников архитектуры.

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PROTECTING FACADES OF CULTURAL HERITAGE OBJECTS FROM THE WIND-DRIVEN RAIN: A REVIEW OF EXPERIMENTAL STUDIES

Abstract. The relevance of the study is due to the fact that erosion of the surface of building materials is a common phenomenon observed on the facades of historic buildings. Climatic changes can lead to an increase in the frequency and intensity of extreme precipitation, which can increase the erosion effects on the facades of buildings due to the wind-driven rain. The purpose of the study is to compare experimental methods for assessing the degree of surface erosion of historic building materials under the influence of wind-driven rainfall. The objectives of the study are to review modern methods for measuring the effect of rain with wind on the surface erosion and reduction of the strength of brick and limestone; to critically analyze the best-known methods for assessing the degree of erosion of the surface of building materials; to offer recommendations for the protection and restoration of damaged facades of cultural heritage objects due to the wind-driven rain.

The significance of the obtained results for architects and designers is that the use of methods to assess the degree of damage to the facades of architectural monuments due to wind-driven rainfall makes it possible to monitor and develop measures to protect objects of cultural heritage.

Keywords: wind-driven rain, erosion of masonry, protection of facades of monuments.

СПИСОК ЛИТЕРАТУРЫ

1. Haugen A., Mattsson J. Preparations for climate change's influences on cultural heritage // International Journal of Climate Change Strategies and Management. 2011. Vol. 3. No. 4. Pp. 386–401. doi:10.1108/17568691111175678
2. Brimblecombe P., Grossi C. M., Harris I. Climate change critical to cultural heritage // Survival and sustainability: environmental concerns in the 21st century. 2011. Pp. 195–205. Springer.
3. Sesana E., Gagnon A., Ciantelli C., Cassar J., Hughes J. Climate change impacts on cultural heritage: A literature review // WIREs Climate Change. 2021. No. 12 (1). 29 p. doi:10.1002/wcc.710
4. Camuffo D. Climate change, human factor, and risk assessment // Microclimate for cultural heritage. 2019. Pp. 303–340. Elsevier.
5. Spezzano P. Mapping the susceptibility of UNESCO World Cultural Heritage sites in Europe to ambient (outdoor) air pollution // Science of The Total Environment. 2021. Vol. 754. 142345. doi:10.1016/j.scitotenv.2020.142345
6. Vidović K., Hočević S., Menart E., Drventić I., Grgić I., Kroflić A. Impact of air pollution on outdoor cultural heritage objects and decoding the role of particulate matter: a critical review // Environmental Science and Pollution Research. 2022. Vol. 29. Pp. 46405–46437. doi:10.1007/s11356-022-20309-8
7. Cutler N.A., Viles H.A., Ahmad S., McCabe S., Smith B. J. Algal «greening» and the conservation of stone heritage structures // Science of the Total Environment. 2013. Vol. 442. Pp. 152–164. doi:10.1016/j.scitotenv.2012.10.050
8. Стrogанов В.Ф., Бойчук В.А., Сагадеев Е.В. Биоповреждение древесных материалов и конструкций // Известия КГАСУ. 2014. № 2 (28). С. 185–193.
9. Стrogанов В.Ф., Сагадеев Е.В., Вахитов Б.Р. Применение модельных сред для оценки биостойкости минеральных строительных материалов // Известия КГАСУ. 2017. № 3 (41). С. 196–202.
10. Prieto B., Vázquez-Nion D., Fuentes E., Durán-Román A.G. Response of subaerial biofilms growing on stone-built cultural heritage to changing water regime and CO₂ conditions // International Biodeterioration & Biodegradation. 2020. Vol. 148. 104882. doi:10.1016/j.ibiod.2019.104882
11. Бессонов И.В., Баранов В.С., Баранов В.В., Князева В.П., Ельчищева Т.Ф. Причины появления и способы устранения высололов на кирпичных стенах зданий // Жилищное строительство. 2014. № 7. С. 39–43.
12. Menéndez B. Estimators of the impact of climate change in salt weathering of cultural heritage // Geosciences. 2018. No. 8 (11). Pp. 401. doi:10.3390/geosciences8110401
13. Tang W., Davidson C.I., Finger S., Vance K. Erosion of limestone building surfaces caused by wind-driven rain: 1. Field measurements // Atmospheric Environment. 2004. Vol. 38. Issue 33. Pp. 5589–5599. doi:10.1016/j.atmosenv.2004.06.030
14. Tang W., Davidson C.I. Erosion of limestone building surfaces caused by wind-driven rain: 2. Numerical modeling // Atmospheric Environment. 2004. Vol. 38. Issue 33. Pp. 5601–5609. doi:10.1016/j.atmosenv.2004.06.014
15. Erkal A., D'Ayala D., Sequeira L. Assessment of wind-driven rain impact, related surface erosion and surface strength reduction of historic building materials // Building and Environment. 2012. Vol. 57. Pp. 336–348. doi:10.1016/j.buildenv.2012.05.004
16. Никитин В.И., Кофанов В.А. Об учете косого дождя и капиллярных свойств материалов при оценке влагосодержания ограждающих конструкций // Вестник БГТУ. Строительство и архитектура. 2013. № 1 (79). С. 91–95.
17. Куприянов В.Н., Петров А.С., Чебышева Д.Г. Влияние дождей на процесс старения и разрушения материалов наружных стен. Расчет количества дождей // Эксперт: теория и практика. 2020. № 1 (4). С. 28–32.
18. Blocken B., Dezsö G., Beeck J. van, Carmeliet J. Comparison of calculation models for wind-driven rain deposition on building facades // Atmospheric Environment. 2010. Vol. 44. Issue 14. Pp. 1714–1725. doi:10.1016/j.atmosenv.2010.02.011
19. Gholamalipour P., Ge H., Stathopoulos T. Wind-driven rain (WDR) loading on building facades: A state-of-the-art review // Building and Environment. 2022. Vol. 221. 109314. doi:10.1016/j.buildenv.2022.109314
20. Baheru T., Chowdhury A.G., Pinelli J.-P., Bitsuamlak G. Distribution of wind-driven rain deposition on low-rise buildings: Direct impinging raindrops versus surface runoff // Journal of Wind Engineering and Industrial Aerodynamics. 2014. Vol. 133. Pp. 27–38. doi:10.1016/j.jweia.2014.06.023
21. Abuku M., Janssen H., Poesen J., Roels S. Impact, absorption and evaporation of raindrops on building facades // Building and Environment. 2009. Vol. 44. Issue 1. Pp. 113–124. doi:10.1016/j.buildenv.2008.02.001
22. Artesani A., Di Turo F., Zucchelli M., Traviglia A. Recent Advances in Protective Coatings for Cultural Heritage – An Overview // Coatings. 2020. No. 10 (3). 217. doi:10.3390/coatings10030217
23. Pino F., Fermo P., Russa M.L., Ruffolo S., Comite V., Baghdachi J., Pecchioni E., Fratini F., Cappelletti G. Advanced mortar coatings for cultural heritage protection. Durability towards prolonged UV and outdoor exposure // Environmental Science and Pollution Research. 2016. No. 24 (14). Pp. 12608–12617. doi:10.1007/S11356-016-7611-3
24. Kahangi Shahreza S., Niklewski J., Molnár M. Experimental investigation of water absorption and penetration in clay brick masonry under simulated uniform water spray exposure // Journal of Building Engineering. 2021. Vol. 43. doi:10.1016/j.jobe.2021.102583

25. Apostolopoulou M., Aggelakopoulou E., Bakolas A., Moropoulou A. Compatible mortars for the sustainable conservation of stone in masonry // Advanced Materials for the Conservation of Stone. 2018. Pp. 97–123. Springer. doi:10.1007/978-3-319-72260-3_5
26. Ge H., Chiu V., Stathopoulos T. Effect of overhang on wind-driven rain wetting of facades on a mid-rise building: Field measurements // Building and Environment. 2017. Vol. 118. Pp. 234–250. doi:10.1016/j.buildenv.2017.03.034

REFERENCES

1. Haugen A., Mattsson J. Preparations for climate change's influences on cultural heritage. *International Journal of Climate Change Strategies and Management*. 2011. Vol. 3. No. 4. Pp. 386–401. doi:10.1108/17568691111175678.
2. Brimblecombe P., Grossi C. M., Harris I. Climate change critical to cultural heritage. *Survival and sustainability: environmental concerns in the 21st century*. 2011. Pp. 195–205. Springer.
3. Sesana E., Gagnon A., Ciantelli C., Cassar J., Hughes J. Climate change impacts on cultural heritage: A literature review. *WIREs Climate Change*. 2021. No. 12 (1). 29 p. doi:10.1002/wcc.710.
4. Camuffo D. Climate change, human factor, and risk assessment. *Microclimate for cultural heritage*. 2019. Pp. 303–340. Elsevier.
5. Spezzano P. Mapping the susceptibility of UNESCO World Cultural Heritage sites in Europe to ambient (outdoor) air pollution. *Science of The Total Environment*. 2021. Vol. 754. 142345. doi:10.1016/j.scitotenv.2020.142345
6. Vidović K., Hočević S., Menart E., Drventić I., Grgić I., Kroflić A. Impact of air pollution on outdoor cultural heritage objects and decoding the role of particulate matter: a critical review. *Environmental Science and Pollution Research*. 2022. Vol. 29. Pp. 46405–46437. doi:10.1007/s11356-022-20309-8
7. Cutler N.A., Viles H.A., Ahmad S., McCabe S., Smith B. J. Algal «greening» and the conservation of stone heritage structures. *Science of the Total Environment*. 2013. Vol. 442. Pp. 152–164. doi:10.1016/j.scitotenv.2012.10.050
8. Stroganov V.F., Boichuk V.A., Sagadeev E.V. Biodegradation of wooden materials and structures. *Izvestiya KGASU*. 2014. No. 2 (28). Pp. 185–193.
9. Stroganov V.F., Sagadeev E.V., Vahitov B.R. Application of model mediums for the biostability assessment of mineral construction materials. *Izvestiya KGASU*. 2017. No. 3 (41). Pp. 196–202.
10. Prieto B., Vázquez-Nion D., Fuentes E., Durán-Román A.G. Response of subaerial biofilms growing on stone-built cultural heritage to changing water regime and CO₂ conditions. *International Biodegradation & Biodegradation*. 2020. Vol. 148. 104882. doi:10.1016/j.ibiod.2019.104882
11. Bessonov I.V., Baranov V.S., Baranov V.V., Knyazeva V.P., Elchischeva T.F. Reasons and eliminate efflorescence on the brick walls of buildings. *Housing Construction*. 2014. No. 7. Pp. 39–43.
12. Menéndez B. Estimators of the impact of climate change in salt weathering of cultural heritage. *Geosciences*. 2018. No. 8 (11). 401. doi:10.3390/geosciences8110401
13. Tang W., Davidson C.I., Finger S., Vance K. Erosion of limestone building surfaces caused by wind-driven rain: 1. Field measurements. *Atmospheric Environment*. 2004. Vol. 38. Issue 33. Pp. 5589–5599. doi:10.1016/j.atmosenv.2004.06.030
14. Tang W., Davidson C.I. Erosion of limestone building surfaces caused by wind-driven rain: 2. Numerical modeling. *Atmospheric Environment*. 2004. Vol. 38. Issue 33. Pp. 5601–5609. doi:10.1016/j.atmosenv.2004.06.014
15. Erkal A., D'Ayala D., Sequeira L. Assessment of wind-driven rain impact, related surface erosion and surface strength reduction of historic building materials. *Building and Environment*. 2012. Vol. 57. Pp. 336–348. doi:10.1016/j.buildenv.2012.05.004
16. Nikitin V.I., Kofanov V.A. On consider of driving rain and capillary properties of materials when assessing moisture enclosing structures. *Vestnik BrSTU. Construction and Architecture*. 2013. No. 1 (79). Pp. 91–95.
17. Kupriyanov V.N., Petrov A.S., Chebysheva D.G. Rain impact on aging and destruction of external walls materials. The amount of rain calculation. *Expert: Theory and Practice*. 2020. No. 1 (4). Pp. 28–32. doi:10.24411/2686-7818-2020-10004
18. Blocken B., Dezsö G., Beeck J. van, Carmeliet J. Comparison of calculation models for wind-driven rain deposition on building facades. *Atmospheric Environment*. 2010. Vol. 44. Issue 14. Pp. 1714–1725. doi:10.1016/j.atmosenv.2010.02.011
19. Gholamalipour P., Ge H., Stathopoulos T. Wind-driven rain (WDR) loading on building facades: A state-of-the-art review. *Building and Environment*. 2022. Vol. 221. 109314. doi:10.1016/j.buildenv.2022.109314
20. Baheru T., Chowdhury A.G., Pinelli J.-P., Bitsuamlak G. Distribution of wind-driven rain deposition on low-rise buildings: Direct impinging raindrops versus surface runoff. *Journal of Wind Engineering and Industrial Aerodynamics*. 2014. Vol. 133. Pp. 27–38. doi:10.1016/j.jweia.2014.06.023
21. Abuku M., Janssen H., Poessens J., Roels S. Impact, absorption and evaporation of raindrops on building facades. *Building and Environment*. 2009. Vol. 44. Issue 1. Pp. 113–124. doi:10.1016/j.buildenv.2008.02.001.
22. Artesani A., Di Turo F., Zucchelli M., Traviglia A. Recent Advances in Protective Coatings for Cultural Heritage – An Overview. *Coatings*. 2020. No. 10 (3). 217. doi:10.3390/coatings10030217

23. Pino F., Fermo P., Russa M.L., Ruffolo S., Comite V., Baghdachi J., Pecchioni E., Fratini F., Cappelletti G. Advanced mortar coatings for cultural heritage protection. Durability towards prolonged UV and outdoor exposure. *Environmental Science and Pollution Research*. 2016. No. 24 (14). Pp. 12608–12617. doi:10.1007/S11356-016-7611-3
24. Kahangi Shahreza S., Niklewski J., Molnár M. Experimental investigation of water absorption and penetration in clay brick masonry under simulated uniform water spray exposure. *Journal of Building Engineering*. 2021. Vol. 43. doi:10.1016/j.jobe.2021.102583
25. Apostolopoulou M., Aggelakopoulou E., Bakolas A., Moropoulou A. Compatible mortars for the sustainable conservation of stone in masonry. *Advanced Materials for the Conservation of Stone*. 2018. Pp. 97–123. Springer. doi:10.1007/978-3-319-72260-3_5
26. Ge H., Chiu V., Stathopoulos T. Effect of overhang on wind-driven rain wetting of facades on a mid-rise building: Field measurements. *Building and Environment*. 2017. Vol. 118. Pp. 234–250. doi:10.1016/j.buildenv.2017.03.034

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